Chapter 10: Coastal Priorities

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SUMMARY

This chapter focuses on two Northern Everglades estuaries, the St. Lucie and Caloosahatchee River Estuaries. Annual reporting on these estuaries is mandated under the Northern Everglades and Estuaries Protection Program (373.4595, Florida Statutes). For both the St. Lucie Estuary (SLE) and Caloosahatchee River Estuary (CRE), outflows from Lake Okeechobee have a profound influence on circulation and transport, water quality, and biotic resources. In addition to an update on relevant watershed construction projects, this chapter contains two primary parts summarizing research and monitoring in the two estuaries. The first part focuses on current efforts in the watershed to improve the quality, quantity, timing, and delivery of water to the estuaries and the current physical (water quality and hydrology) and ecological (oysters and submerged aquatic vegetation) condition of the two estuaries. Monitoring data were analyzed at three basic scales including dry (November–April) versus wet (May–October) seasons, over the last three water years, and relative to interannual reference values.

The current regulation schedule for Lake Okeechobee (2008 LORS) allows considerable flexibility in low level discharges to the CRE during the dry season. The Final Adaptive Protocols for Lake Okeechobee Operations (SFWMD, 2010) provide some guidance for making these releases. The second part of this chapter describes an Adaptive Protocol Study conducted by South Florida Water Management District (District or SFWMD) staff to investigate the effects of low level releases of fresh water from Lake Okeechobee on water column ecology in the CRE on timescales of 3–5 days during the dry season.

ST. LUCIE ESTUARY

Rainfall over the St. Lucie River Watershed varied both seasonally and annually from Water Year 2010 (WY2010) (May 1, 2009–April 30, 2010) through WY2012. A wetter than average dry season occurred in WY2010. WY2011 was drier than average in both the wet and dry seasons. In WY2012, rainfall in both the wet and dry seasons compared favorably with long-term averages.

The total amount of fresh water entering the SLE was less than the long-term average in all three water years and particularly reduced in WY2012, when there were no discharges from Lake Okeechobee. Patterns of reduced rainfall and freshwater input drove salinity increases in the SLE that were very high during the WY2011 dry season and the beginning of WY2012. The 8–25 salinity envelope at the US 1 Bridge was maintained for 74 percent of the days in WY2012.

Nutrient loading is driven by freshwater inflow to the SLE. Like freshwater inflow, total nitrogen (TN) and total phosphorus (TP) loading was less than the long-term average in all three water years. TN concentrations in the North Fork and middle estuary fluctuated around the Total Maximum Daily Load (TMDL) target of 0.72 milligrams per liter (mg/L), but were much lower near the St. Lucie Inlet. TP concentrations were greater than the TMDL target of 0.08 mg/L in the North Fork and middle estuary, but were much lower near the inlet. Chlorophyll *a* concentrations were generally lower than the Impaired Waters Rule value.

Oyster densities increased throughout the period of record although overall oyster condition index was observed to be decreasing late in 2011. Overall increasing salinity conditions throughout the period of record led to increased distribution and dominance of salt tolerant seagrass species (e.g., shoal grass and manatee grass) both within the SLE near the inlet and in the Indian River Lagoon.

CALOOSAHATCHEE RIVER ESTUARY

Total annual rainfall over the Caloosahatchee River Watershed during WY2012 was close to the long-term average. Rainfall was lower than average in WY2011, and greater than average in WY2010. The distribution of rainfall between the two seasons also varied. Wet season rainfall for WY2010 and WY2012 were similar to the long-term average. The relatively low total rainfall in WY2011 was due to a lower than average wet season rainfall. The relatively higher total rainfall in WY2010 was due to higher than average dry season rainfall that accompanied El Niño conditions. Rainfall during the WY2012 dry season was considerably reduced relative to the long-term average.

Total discharge at the S-79 structure was lower than the long-term average in all three water years. In particular, freshwater discharge in WY2012 was lower than the two previous water years with reduced inflow rates in both the wet and dry seasons. While total discharge was similar in WY2010 and WY2011, the contribution from Lake Okeechobee was smaller in WY2010 (13 percent) than in WY2011 (45 percent).

Exceedances of critical salinity criteria in the CRE reflected dry season rainfall patterns. Salinity was lowest during WY2010 when dry season rainfall was highest and highest during WY2012 when dry season rainfall was lowest. A period of no discharge at the beginning of WY2012 (May–June 2011) also contributed to the high number of exceedances in that water year.

TN and TP loadings to the CRE decreased during each of the past three water years. This pattern reflected lower than average discharge as TN loading at S-79 in WY2012 was much lower than the long-term average [1,008.7 versus 2,538.1 million tons (mtonnes)]. Similarly, TP loading to the CRE in WY2012 was only 47 percent of the long-term average with almost 87 percent less TP contributed by Lake Okeechobee releases.

A significant algal bloom occurred upstream of S-79 in May and June 2011 (WY2012). This bloom was associated with a period of greatly reduced freshwater inflow and high seasonal temperatures greater than 27 degrees Celsius (^{o}C).

Live densities of oysters ranged from approximately 500 to 3,000 oysters per square meter across the four sites with overall reduced densities in the WY2012 wet season (July 2011). These reduced densities may have resulted from the high salinities experienced during the previous dry season (WY2011). Accompanying high salinity are an increase in predation rates and intensity of parasitic infection. After disappearing from the upper estuary in 2009, tape grass reappeared during WY2011 but was absent in WY2012. The loss of tape grass may be caused by the high salinities (greater than 15) that occurred in the WY2011 dry season.

ADAPTIVE PROTOCOL STUDY

There is little information on the effects of low level releases on either the salinity distributions or water column ecology in the CRE. The Adaptive Protocols Study utilized a combination of a flow-through system for rapid characterization of surface waters and a series of vertical profiling stations to detect changes in estuarine hydrography, water quality, and plankton attributes on seven research cruises from January through April 2012.

The effects of freshwater inflow were evident in both the range and the longitudinal oscillations in salinity from 10 kilometers (km) downstream of S-79 to San Carlos Bay. As in many estuaries, the area of maximum zooplankton biomass was located just downstream of the chlorophyll *a* maximum. Of the seven cruises, comparatively high in situ chlorophyll *a* concentrations approaching 60 micrograms per liter (μg/L) were observed within 5 km downstream of S-79 on the first (January 12, 2012) and last (April 12, 2012) dates. Two different hydrographic conditions contributed to the observed patterns. Water column stratification from low level freshwater inflows preceding the first cruise could have created conditions where phytoplankton proliferated in the surface water. By contrast, the high concentrations observed in April occurred in a time of no inflow but increased water temperature throughout the estuary.

While the study was instructive, it occurred during part of only one South Florida dry season. Future studies should concentrate on gradients of salinity, chlorophyll *a*, zooplankton, and fish larvae under various flow regimes on sub-weekly, monthly, and seasonal timescales utilizing the state-of-the-art flow-through technology.

INTRODUCTION

In accordance with the Northern Everglades and Estuaries Protection Program [Section 373.4595, Florida Statutes (F.S.)], this chapter provides an annual summary of the hydrology, water quality, and aquatic habitat in the St. Lucie and Caloosahatchee River Estuaries (SLE and CRE, respectively) (**Figure 10-1**). Estuaries such as these are important social, economic, and ecological features of the South Florida coastal landscape. The once abundant fringing wetlands and shallow flats, water column and benthos, submersed aquatic vegetation (SAV), and oyster reefs indicative of South Florida estuaries provide essential habitat for a variety of valuable faunal populations (Tolley et al., 2006; Rozas et al., 2006, 2012). The distribution and status of these valuable ecosystem components are modulated by complex combinations of climate and weather, freshwater management, and estuarine circulation (Childers et al., 2006; Phlips et al., 2011; Buzzelli, 2011).

In the case of the SLE and CRE, outflows from Lake Okeechobee have profound influence on estuarine physics, water quality, and biotic resources. When summarizing the environmental conditions in these estuaries it is important to consider that the dynamics of climatic drivers (e.g., rainfall and temperature) vary over timescales ranging from that of atmospheric frontal passages (synoptic scale in days) to longer-term climatic oscillations (El Niño scale of 3–5 years) and decadal patterns. Thus, the wet-dry subtropical seasonality typical of South Florida estuaries should be contrasted annually to both longer-term (greater than 10 years) and shorter-term (1–3 years) patterns.

Annual reporting on the SLE and CRE is mandated under the Northern Everglades and Estuaries Protection Program (373.4595 F.S.). In 2007, the Florida legislature expanded the existing Lake Okeechobee Protection Act to include river watershed protection programs for the Caloosahatchee and St. Lucie Rivers. The legislation required the creation of the Caloosahatchee River Watershed Protection Plan (RWPP) (SFWMD et al., 2009a, 2012a) and the St. Lucie RWPP (SFWMD et al., 2009b, 2012b). These plans build on existing approaches and consolidate restoration efforts throughout the entire Northern Everglades system. Each plan includes three

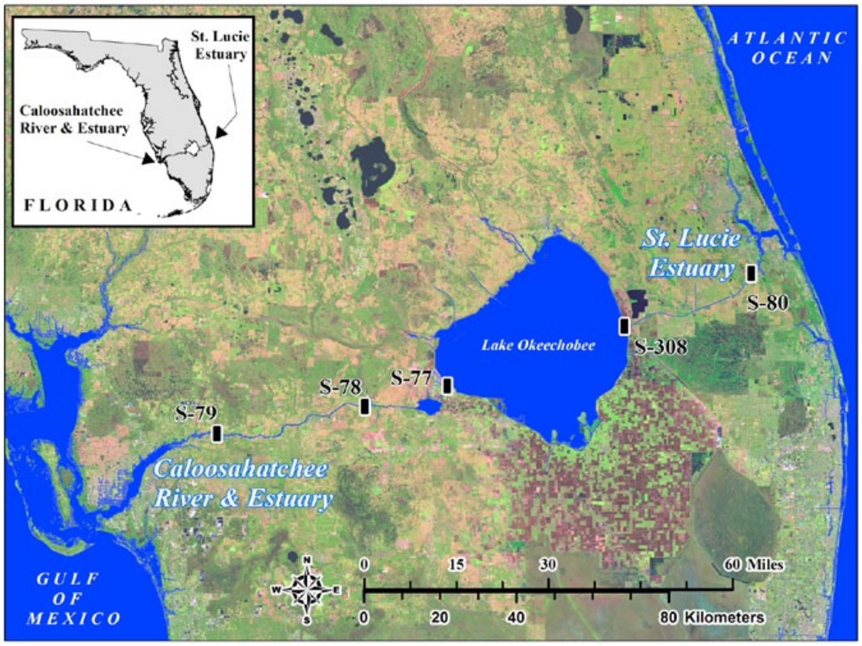

Figure 10-1. Map showing Lake Okeechobee, the St. Lucie Estuary (SLE), and the Caloosahatchee River Estuary (CRE) and in South Florida. Outflow from the lake is regulated at structures S-308 (east) and S-77 (west). Freshwater discharge at the estuarine heads is through structures S-80 eastward to the SLE and S-79 westward to the CRE.

components: (1) a Pollutant Source Control Program, which is a multifaceted approach for improving the management of pollution sources within the river watershed; (2) the Construction Project, which identifies water quality improvement and storage projects to improve the hydrology, water quality, and aquatic habitats within the watersheds; and (3) a Research and Water Quality Monitoring Program, which primarily assesses progress towards achieving the water quality and storage targets and the plans, programs, and other responsibilities in the RWPPs.

The first part of this chapter focuses on the status of the Construction Project component of the protection plans and the current physical (water quality and hydrology) and ecological (oysters and SAV) condition of the two estuaries. This part also serves to meet the annual Northern Everglades and Estuaries Protection Program reporting requirements for the river watersheds [373.4595 (6), F.S.]. The updates to the Construction Project components focus on activities that occurred during Water Year 2012 (WY2012) (May 1, 2011–April 30, 2012).

The structure and content of the SLE and CRE sections of this chapter are identical with summary information on watershed rainfall, freshwater discharge to the estuaries, salinity distributions, total nitrogen (TN) and total phosphorus (TP) loads, estuarine water column concentrations, patterns of SAV community composition, and the status of oyster reef habitat. Monitoring data from both estuaries were summarized by water year. A water year is the period of record (POR) from May 1 of one year to April 30 of the next (WY2012 began on May 1, 2011 and ended on April 30, 2012). The categorical variable "season" was defined by splitting the months into dry (November–April) and wet (May–October) groupings for all calculations. Monitoring data were graphed in time series format over the past three water years (WY2010–WY2012) to examine recent intra- and interannual patterns. Three timescales were used to summarize by water year in tabular format (long-term, WY2010, WY2011, and WY2012). Long-term reporting (multi-annual to decadal timescales) depended upon data availability for the variable of interest. PORs were chosen to maintain consistency between the two estuarine systems. Values were summed (rates of rainfall, inflow, and loadings) or averaged (concentrations of salinity, TN, TP, SAV, and oysters) by water year and season in order to compare and contrast among the three timescales.

The second part of the document describes an Adaptive Protocol Study (AP Study) conducted by South Florida Water Management District (District or SFWMD) staff to investigate the effects of low level releases of fresh water to the CRE during the dry season. The regulation schedule for water levels in Lake Okeechobee (2008 LORS) has considerable flexibility allowing for releases of up to 450 cubic feet per second (cfs) of water from Lake Okeechobee to the CRE at the Franklin Lock and Dam (S-79). The purpose of these releases is to decrease the probability of higher discharges during the wet season and moderate potential deleterious effects of high salinity in the upper CRE. The Final Adaptive Protocols for Lake Okeechobee Operations document (SFWMD, 2010) provides a decision flowchart to guide when releases are made.

Unfortunately, there is little information on the effects of low level releases on either the salinity distribution or ecology of the CRE. Therefore, quantifying how to optimize releases for environmental benefits provided the impetus for the AP Study. This study was an intensive and concerted effort to link low level releases from Lake Okeechobee to CRE water column ecology on synoptic timescales in the WY2012 dry season. District personnel utilized a state-of-the-art system for rapid acquisition of in situ water quality data. The flow-through system allows researchers to obtain water column data continuously at high speeds and rapidly cover an entire water body. Given this flexible technology, seven research cruises from S-79 to Shell Point in the CRE were conducted during January–April 2012 while releases of water were in progress. Patterns of water quality and plankton abundances were interpreted relative to cruise date, distance downstream, and freshwater inflow.

ST. LUCIE AND CALOOSAHATCHEE ESTUARIES

Located in southeastern Florida in Martin and St. Lucie counties, the SLE comprises a major tributary to the Southern Indian Lagoon (SIRL) (Sime, 2005; Ji et al., 2007) (**Figure 10-2**). Historically, the SLE was a freshwater system exposed to the coastal ocean only through ephemeral passes in the barrier islands. The St. Lucie Inlet was permanently opened in 1892 to provide a connection between the SLE and coastal ocean. The SLE is now a partially mixed micro-tidal estuary having a semi-diurnal tide with amplitude of 0.38 meters (m). The SLE is geographically divided into four distinct segments: North Fork, South Fork, middle estuary, and lower estuary near the St. Lucie Inlet. Total surface area of the estuary is 29 square kilometers (km^2) [2,900 hectares (ha)] with an average depth of 2.4 m. The flushing time of the SLE ranges from 2 to 20 days (Ji et al., 2007).

To accommodate population growth and coastal development, the St. Lucie River Watershed has been highly altered from natural sloughs and wetlands into a system of 12 modified sub-basins. The SLE receives drainage from a comparatively large area as the ratio between watershed area and SLE surface area is approximately 150 to 1 (150:1) (i.e., Tampa Bay has a ratio of 5.5:1). Periodic high volume water releases from Lake Okeechobee have altered historical wet season and dry season water flows to the SLE. These changes in flow and resultant variations in salinity and water quality are associated with habitat loss, decreased biodiversity, and increased prevalence of marine diseases within the estuary (Sime, 2005; SFWMD, 2012a). Connections to and drainage from the watershed have led to extreme freshwater inflow, phytoplankton blooms, accumulation of flocculent muck-like sediments, severe loss of seagrass habitat, and a dramatic decline in the extent of oyster beds within the SLE.

The Caloosahatchee River Watershed is located on the lower west coast of Florida in Lee, Charlotte, Collier, Glades, and Hendry counties (Barnes, 2005). The Caloosahatchee River and Estuary have been altered by human activities starting in the 1880s when the river was straightened and deepened losing 76 river bends and 13.2 km of length (Antonini et al., 2002). The first water control structures at Lake Okeechobee (S-77) and Ortona (S-78) were completed in the 1930s. The last structure was completed in 1966 at Olga (S-79) to provide fresh water to Lee County and prevent upstream saltwater intrusion (Antonini et al., 2002). A network of secondary and tertiary canals throughout the Caloosahatchee River Watershed (C-43 Basin) supports agriculture and urban development. The mesohaline and polyhaline estuary downstream of S-79 also has been significantly altered (Chamberlain and Doering, 1998). Early descriptions of the CRE characterize it as barely navigable due to extensive shoals and oyster bars near Shell Point (Sackett, 1888). A navigation channel was dredged and a causeway built across the mouth of San Carlos Bay in the 1960s. Historic oyster bars upstream of Shell Point were mined and removed to be used in the construction of roads.

The present Caloosahatchee River Watershed (C-43 Basin) is a series of linked regional sub-watersheds and includes the S-4 Basin adjacent to Lake Okeechobee, East Caloosahatchee Basin, West Caloosahatchee Basin, Tidal Caloosahatchee Basin downstream of S-79, and Cape Coral Coastal Basin to the north of the CRE (SFWMD et al., 2012b). The Caloosahatchee River spans 70 km from an outflow structure at Lake Okeechobee (S-77) westward to the Franklin Lock and Dam (S-79). The Franklin Lock represents the head of the CRE that extends 42 km downstream to Shell Point where it empties into San Carlos Bay. The surface area of the CRE is 56 km^2 (5,600 ha) with an average depth of 2.7 m. The flushing time ranges from 2 to 30 days (Buzzelli et al., in press A).

USE OF ESTUARINE HABITATS AS INDICATORS OF FRESHWATER FLOW

Knowledge of the environmental conditions that favor biologically productive estuarine habitats [e.g., SAV, oyster reef, and low salinity zone (LSZ)] can be used to help prescribe freshwater inflow criteria and decision making (Doering et al., 2002; Volety et al., 2009; Adams et al., 2009; Gillson, 2011). This is a concept that is being applied particularly to water management in coastal Texas, Australia, South Africa, and South Florida. All these coastal landscapes are characterized by subtropical climate, accelerated development and freshwater consumption, and provide economically valuable ecosystems goods and services (e.g., fisheries and navigation).

The SLE and CRE have different inflow and salinity optima given differences in estuarine geomorphology, volume, flushing, and inflow characteristics. Oyster habitat provided the biotic indicator of salinity and freshwater discharge in the SLE. Oyster physiology, survival, and growth are optimal when salinity fluctuates from 8 to 25 in many estuaries, including the SLE. Systematic analyses of inflows determined that discharge ranging from 350 to 2,000 cfs serves to maintain salinity of 8–25 throughout much of the SLE. The freshwater SAV tape grass (*Vallisneria* americana) provided the indicator habitat to help prescribe freshwater delivery through S-79 to the CRE (Doering et al., 2002). Tape grass is very sensitive to both increased salinity and decreased submarine light availability (Bortone and Turpin, 2000; French and Moore, 2003).

The Caloosahatchee River Minimum Flows and Levels criteria established in 2001 and updated in 2003 has two salinity criteria measured at Fort Myers (SFWMD 2000, 2003). Critical salinity criteria have been established at Fort Myers and at the I-75 Bridge to protect valuable resources and to assist implementation of the Lake Okeechobee Regulation Schedule. The Fort Myers location has two salinity criteria: maintaining daily salinity averages of less than 20 and

30-day salinity averages of less than 10 while the critical salinity criteria at I-75 is less than 5. At the estuary-scale, average monthly inflows of 300–2,800 cfs at S-79 are conducive both to tape grass and favorable for seagrass and oyster habitats in the polyhaline CRE.

RIVER WATERSHED CONSTRUCTION PROJECT UPDATES

Reducing nutrient loading and high discharges to the SLE and CRE requires action at the regional, subregional, and local levels and the Construction Project component contains activities and projects at each of these spatial scales. It focuses on water quality and storage with components that will improve hydrology, water quality, and aquatic habitats within the watershed and estuary. It builds upon the Source Control Program (see Chapter 4 of this volume) and includes water quality projects, local stormwater retrofits, reservoirs, and habitat restoration.

St. Lucie River Watershed Construction Project Update

IRL-S C-44 Reservoir/STA Project

The regional project that will have the greatest benefit for the SLE is the Comprehensive Everglades Restoration Plan (CERP) Indian River Lagoon – South (IRL-S) Project, which is a state-federal partnership to restore the southern portion of the lagoon, the SLE, and the associated watershed. A critical component of the IRL-S Project is the C-44 Reservoir/Stormwater Treatment Area (STA) Project. The objectives of this component are to capture, store, and treat runoff from the C-44 Basin prior to discharge to the SLE. Implementation of this project is expected to reduce damaging freshwater discharges, decrease nutrient load, and maintain desirable salinity regimes. This project, located north of the C-44 canal, includes construction of a 3,400-acre reservoir and an adjacent 6,300-acre STA. The District completed the design for the project components. The United States Army Corps of Engineers (USACE) is responsible for construction and will solicit three contracts over a seven-year period. Initial construction (Contract 1, awarded July 2011) includes the project intake canal, access road, and the Citrus Boulevard Bridge. Contract 2 will include the reservoir, pump station, and discharge canal, while Contract 3 will complete the project by constructing the STA cells. Execution of Contracts 2 and 3 execution is anticipated in 2014 and 2017, respectively.

Local Water Quality and Restoration Projects

There are several local water quality and restoration projects identified in the St. Lucie RWPP including stormwater improvements and retrofits, wastewater improvement projects (septic to sewer), and habitat restoration projects (e.g., muck/sediment removal, oyster habitat creation, and wetland restoration). A complete update of local projects identified in the St. Lucie RWPP can be found in the 2012 St. Lucie RWPP Update (SFWMD et al., 2012a), which can be found in Appendix 10-1 of the *2012 South Florida Environmental Report (SFER) – Volume I*. The Florida Department of Environmental Protection (FDEP) is producing an inventory of water quality projects conducted since 2000 to estimate project-specific load reductions through their Basin Management Action Plan (BMAP). It is anticipated that this inventory for the St. Lucie River Watershed and project associated load reductions will be adopted in the St. Lucie RWPP. Many of the local projects are implemented through a cost-sharing approach with state and federal partners. Four projects that used state, District, and Martin County funds had significant progress during WY2012:

- **Old Palm City Phase 3 Stormwater Quality Improvement Project.** Phase 3 of the this retrofit project addresses water quality and flood attenuation problems within the southern portion of the basin and includes two STAs totaling 6.5 acres and serving 106 acres of residential land. The project was constructed in 2011.

- **North River Shores Vacuum Sewer System.** This project provides sanitary sewer service to about 450 single and multiple family parcels of land in the North River Shores area, eliminating nutrient loading from septic systems to the North Fork of the St. Lucie River. In addition, the project will route wastewater to the North Wastewater Treatment Plant for conversion to irrigation quality reclaimed water. Phase I is complete with 435 sewer lateral connections in place and homeowners had until January 12, 2012, to connect to the new system. Plans to convert the remaining 315 homes (Phase II) are under way and funding is being investigated.
- **Manatee Creek Basin Water Quality Retrofit.** This was a multi-phased project. Phase I included creation a 12-acre STA marsh, creation of a dry detention facility, and infrastructure improvements to convey runoff to treatment facilities for water quality treatment and to reduce flooding. Phases II and III included construction of two STAs: (1) a STA/wet detention system with a prototype denitrification bed to treat runoff from more than 200 acres, and (2) a 5-acre STA serving 40 acres of older residential development to improve water quality and reduce flooding in the New Monrovia subdivision. Phase I was completed in 2011. Phase II is in the final stages with completion dates scheduled for July 2012.
- **Manatee Pocket Dredging.** This project included (1) dredging a 100-foot wide navigation channel that provides navigational and environmental enhancements to the Manatee Pocket and its adjacent waterways as well as important economic benefits for the surrounding communities, (2) removing accumulated muck in areas and at depths where seagrasses might recruit, and (3) adding signage and buoys. The project began in July 2010 and was completed in December 2011.

Caloosahatchee River Watershed Construction Project Update

CERP Caloosahatchee River (C-43) West Basin Storage Reservoir Project

This project consists of an aboveground reservoir [170,000 acre-feet (ac-ft) capacity] located south of the CRE and west of the Ortona Lock (S-78). Excess basin stormwater runoff and regulatory releases from Lake Okeechobee are expected to be captured and stored in the reservoir and released slowly, as needed, to restore and maintain the estuary. The reservoir is also intended to improve the CRE's salinity balance by controlling peak flows during the wet season and providing essential flows during the dry season. To date, all needed land has been acquired, preconstruction test cells have been completed and monitored, project design has been completed, and all permits have been obtained. A Record of Decision was issued by the USACE in April 2011 and an approved project implementation report (USACE and SFWMD, 2010) was submitted in April 2011 to the United States Congress for authorization.

Spanish Creek/Four Corners Initiative

This is a collaborative initiative among the District and Lee and Hendry counties to develop regional approaches for improving water quality and storage in the Caloosahatchee River Watershed. The goal is to expand upon existing conceptual plans to address conveyance, attenuation, and treatment of stormwater runoff from the Spanish Creek and Jacks Branch (County Line Ditch) watersheds using wetland flow-ways. This initiative has two distinct projects: (1) Spanish Creek Restoration (Lee County) and (2) Jacks Branch (County Line Ditch) (Hendry County). Under the Spanish Creek Restoration component, Lee County has been pursuing a project to create wetland flow-ways that will serve to rehydrate the Ruby Daniels Preserve, Bob Jane's Preserve, and Spanish Creek. Alternatives for restoration of Daniels

Preserve are being developed with the goal of having a plan formulated in August 2012. In Fiscal Year 2013 (FY2013) (October 1, 2012–September 30, 2013), the District plans to provide funds to Lee County for the project's initial design; project construction will be addressed in the future, pending availability of funds. Under the Jacks Branch component, Hendry County, in collaboration with the District, has developed 30 percent design plans for improvements to County Line Ditch, which conveys stormwater flows from Jacks Branch Watershed to the Caloosahatchee River. On February 29, 2012, the District executed a cooperative agreement with Hendry County for developing the 100 percent design plans, which are anticipated to be complete in July 2013. Project construction will be addressed in the future pending availability of funds. For more information regarding this initiative, please see the 2012 update to the St. Lucie RWPP (SFWMD et al., 2012a).

C-43 Water Quality Treatment and Testing Facility Project

The District is partnering with Lee County on the development and implementation of the C-43 Water Quality Treatment and Testing Facility Project to investigate and test new strategies for reducing TN in the C-43 canal. This is necessary since the adopted Total Maximum Daily Load (TMDL) for the CRE is based on TN, yet there are many unknowns and uncertainties regarding available technologies to treat the major component of TN, which is dissolved organic nitrogen (DON). Additional data are needed to improve understanding of DON and its effects in aquatic environments. In WY2012, the District contracted a company with expertise in the field of nitrogen and nutrient removal using constructed wetlands to develop a conceptual design for a test facility comprised of mesocosms and test cells that (1) will test and demonstrate wetland technologies that have the potential to effectively remove and/or reduce background TN loading from the facility's C-43 canal inflows; (2) identify the range of hydrological loading rates per unit area to achieve optimal removal/reduction rates; (3) is based on a review of available information and sound science; and (4) is implementable and cost effective on larger scales and/or applicable to other South Florida estuarine systems. The District anticipates that the project will generate nutrient reduction strategies that can be applied to other regional estuaries. For WY2013, the District expects to have a complete conceptual design for a testing facility comprised of mesocosms, test cells, and full-scale cells including vegetation types and testing plans. Full engineering design and permitting of the testing facility is to commence in late WY2013 or early WY2014.

Caloosahatchee Basin Storage/Treatment Initiative

As part of a five-year reserve spend-down plan to dedicate accumulated reserves and cash balances toward restoration and water supply priorities, the SFWMD has identified $19 million available from FY2012 to FY2016 to fund the design and construction of facilities that will provide stormwater storage or treatment on publicly owned lands within the Caloosahatchee Basin. The project builds on concepts identified in prior planning studies and design plans. In coordination with stakeholders, several options have been identified and are undergoing further evaluation and design. Each of these options can be independently implemented and include the Lake Hicpochee Hydrologic Enhancement and the East County Water Control District's Mirror Lakes Stormwater Retention Facility. FY2012 activities included (1) identification of projects in collaboration with stakeholders and completion of basis of design reports and preliminary design for the selected projects, (2) working towards securing a consultant to provide surveying and geotechnical investigation services in support of the design for the Lake Hicpochee component, and (3) initiation of Phase I construction for the Mirror Lakes component, which began in May 2012 and is scheduled for completion in September 2012.

Local Water Quality and Restoration Projects

There are several local water quality and restoration projects identified in the Caloosahatchee RWPP that are similar in type to those described in the SLE *Local Water Quality and Restoration Projects* section above. A complete update of local projects identified in the Caloosahatchee RWPP can be found in the 2012 Caloosahatchee RWPP update (SFWMD et al 2012b), which can be found in Appendix 10-2 of the 2012 SFER – Volume I. As mentioned in the St. Lucie River Watershed Construction Project update, it is anticipated that the BMAP project inventory for the Caloosahatchee River Watershed and the project associated load reductions will be adopted in the Caloosahatchee RWPP.

Many of the local projects are implemented through a cost-sharing approach with state and federal partners. One of particular interest is the Powell Creek Filter Marsh, for which the District is providing one-time cost-share dollars to Lee County. Situated in North Fort Myers, Powell Creek is a natural tributary of the Caloosahatchee River. This project involves construction of an 18-acre filter marsh and enhancement of existing wetlands. Ultimately, water from the creek and associated canal will be diverted through a series of shallow and deep wetlands, allowing sediment to settle and plants to absorb nutrients, before flowing back into the creek and downstream to the river. In addition to water quality and habitat improvements, the project will increase water storage and provide recreational opportunities. Construction began in January 2012 and is anticipated to be complete in September 2012.

Alternative Nutrient Reduction Technology

Finally, assessment of new technologies is essential to successfully achieve nutrient reductions goals in the Northern Everglades. The SFWMD's New Alternative Treatment Assessment (NATA) initiative provides a forum to explore additional nutrient reduction technologies. Twelve technologies have been reviewed by the review team to date and five are currently being tested either in bench studies, or in situ. Technologies being explored further under NATA include hybrid wetland treatment technology, proprietary clay-like materials that bind nitrogen and phosphorus, electro-coagulation technology, and permeable reactive barriers. More information on NATA is provided in Chapter 8 of this volume.

ST. LUCIE ESTUARY HYDROLOGY, WATER QUALITY AND AQUATIC HABITAT

To better manage freshwater inflows to the SLE, flow and salinity envelopes for the middle estuary were developed based on the requirements of the eastern oyster (*Crassostrea virginica*) (USACE and SFWMD, 2004). Based on relationships between inflows and estuarine salinity, preferred monthly average inflows from the watershed, groundwater, and Lake Okeechobee should range from 350 to 2,000 cfs. These flows will maintain salinity in the range of 8–25 at the Roosevelt Bridge.

The FDEP developed a TMDL for the St. Lucie River Watershed. The TMDL technical document was finalized (FDEP, 2008) and the rule was adopted [Chapter 62-304.705, Florida Administrative Code (F.A.C.)] in 2009. The TMDL water quality targets [0.081 milligrams per liter (mg/L) TP and 0.72 mg/L TN] are applied at the Roosevelt Bridge (at US Highway 1) and upstream to the major water control structures.

Historically, seagrass meadows and oyster reefs are salient features of the landscape in South Florida estuaries. To evaluate the ecological condition of the SLE, SAV and oysters are routinely monitored. SAV are commonly monitored to gauge the health of estuarine systems (Tomasko et al., 1996) and their environmental requirements can form the basis for water quality goals (Dennison et al., 1993). Oyster beds are a good indicator of estuarine condition as the distribution and abundance of the eastern oyster have ecosystem-scale implications. Oyster beds filter water and suspended solids, couple the water column to the benthos, and provide living aquatic habitat (Peterson et al., 2003; Coen et al., 2007).

Methods

A suite of external drivers and ecological responses are monitored in the St. Lucie River Watershed and Estuary. These variables include rainfall, freshwater discharge, and nutrient loading as external drivers, and patterns of salinity, estuarine nutrient concentrations, oyster habitat status, and SAV community composition in the SIRL as the ecological responses. Salinity gradients provide a conservative property useful to connect freshwater inflow to estuarine flushing time and biological resource tolerance ranges (Wilbur, 1992; Jassby et al., 1995; Kimmerer, 2002; Hagy and Murrell, 2007; Pollack et al., 2011).

Next-Generation Radar (NEXRAD) rainfall data from WY1997–WY2012 were obtained through the District’s hydrometeorologic database, DBHYDRO, for the seven distinct NEXRAD units that comprise the St. Lucie River Watershed: Basins 4–6, C-23, C-24, C-44, North Fork, South Coastal, and South Fork (**Figure 10-2, left panel**). Total rainfall over the whole watershed was calculated using an area-weighted method where the daily rainfall from each sub-basin was scaled by its size relative to the total area of the combined watershed. The derived total daily rainfall was categorized by water year and season to calculate average and total values.

Freshwater discharge is monitored at the major structures of S-80 (C-44 Basin), S-48 (C-23 Basin), and S-49 (C-24 Basin) (**Figure 10-2**). Average daily inflow spanning from WY1996 to WY2012 from these structures were summed and used to evaluate intra- and interannual variations in overall inflow and to quantify total inflow of surface water to the SLE each water year. Total daily discharges were categorized by water year and season. Daily TN and TP loads were calculated using daily inflows at the structures, and TN and TP concentrations were determined from water samples at the structures. Daily loads from WY1996–WY2012 were categorized by water year to evaluate temporal variations at different timescales. To estimate the contribution of water released from Lake Okeechobee on freshwater inflows and nutrient loads to the SLE, flows and loads at S-80 were parsed into those deriving from the C-44 Basin and those from the lake using data from S-308.

Surface and bottom salinity observations are recorded every 15 minutes at three stations in the SLE: HR1, Roosevelt Bridge, and A1A Bridge (**Figure 10-2, right panel**). Data reporting and analyses focused on WY2010–WY2012 at the Roosevelt Bridge. First, daily surface and bottom salinity values were averaged together. Second, the monthly average and standard deviation of salinity were calculated for each station to produce a time series over the past three water years. Third, salinity data were categorized by water year and season to compare and contrast intra- and interannual patterns. Fourth, an exponential curve was fit to the relationship between average total monthly discharge and average monthly salinity at the Roosevelt Bridge. The ranges in both values and shapes of the resulting curves were contrasted among WY2010, WY2011, and WY2012. Daily salinity at the US 1 Bridge for WY2010–WY2012 was presented along with time series for density and condition of oysters, and community composition of SAV.

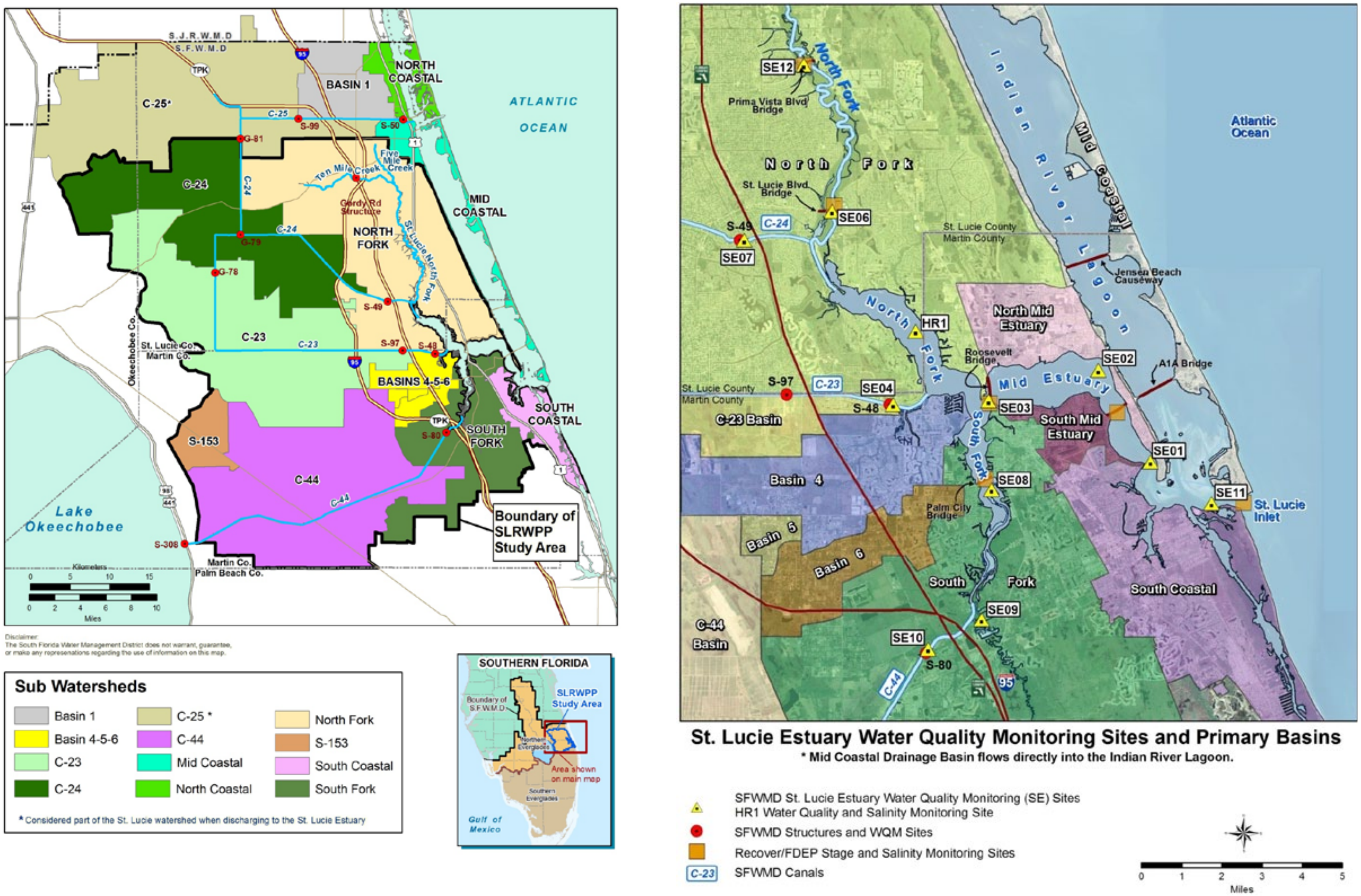

Figure 10-2. St. Lucie River Watershed in southeastern Florida (left panel) and SLE boundaries including structures, water quality stations, and locations of continuous salinity monitoring (right panel). The SLE has four distinct segments: North Fork, South Fork, middle estuary, and lower estuary near the mouth of the St. Lucie Inlet.

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Water is sampled at mid-depth at 12 stations in the SLE at approximately monthly intervals (**Figure 10-2, right panel**). To evaluate water quality, three representative stations were chosen (HR1, SE03, and SE11). Concentrations of TN, TP, and chlorophyll *a* (Chl*a*) from WY1999–WY2012 from each of the stations were included in the analyses (SFWMD, 2011). The long-term median value was calculated along with the interquartile range (difference between the 75^{th} and 25^{th} percentiles) to provide an envelope of historical values. Average monthly concentrations from WY2010–WY2012 were superimposed graphically to contrast patterns among the timescales. To further characterize the status of water quality in the SLE, concentrations were compared to the target TMDL concentrations of 0.72 mg/L TN and 0.081 mg/L TP and the Impaired Waters Rule (IWR) (Chapter 62-303, F.A.C.) value for Chl*a* of 11.0 micrograms per liter (μg/L).

Oyster monitoring has been ongoing in three segments of the SLE (middle estuary, South Fork, and North Fork) since WY2005 (**Figure 10-3, left panel**). The condition index (CI) is a commonly used indicator of oyster physiological status that has been monitored at these sites since WY2005 (Wilson et al., 2005; Volety et al., 2009; SFWMD et al., 2009a). Monitoring for CI ended in November 2011. Live oyster densities have been estimated at each of these sites since WY2005. Time series for each of these variables were derived for each site over the available POR.

Eight sites were visited in the SLE and SIRL including Joe's Point, Ocean Breeze Park, Site 1, Boy Scout Island, and St. Lucie Inlet Northeast monitored bi-monthly, and Boy Scout Island, St. Lucie Inlet Southeast, and Willoughby Creek monitored monthly (**Figure 10-3, right panel**). A large quadrant grid [3 m x 3 m = 9 square meters (m^2)] subdivided into 25 equal sub-quadrants was deployed at randomly selected locations within each of the eight sites. The percent occurrence for each seagrass species within each large quadrant grid is determined by the percentage of total sub-quadrants containing each species. The average and standard error of percent occurrence for each species was calculated from the 30 locations at each monitoring site.

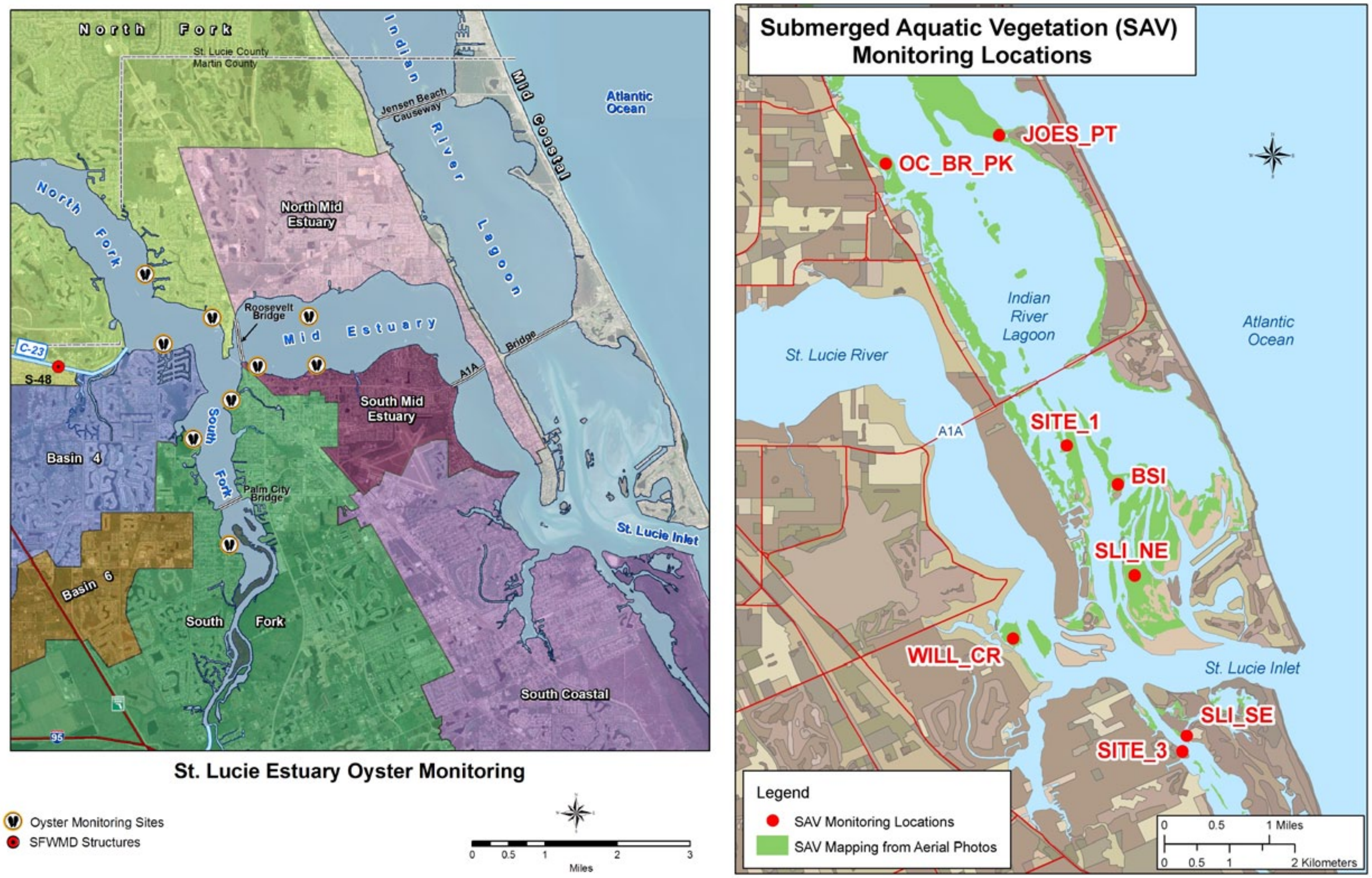

Figure 10-3. Locations for oyster monitoring locations (left panel), and submersed aquatic vegetation (SAV) (right panel) in the Southern Indian River Lagoon (SIRL) adjacent to the SLE. [Key to station names: Boy Scout Island (BSI), Joes Point (JOES_PT), Ocean Breeze Park (OC_BR_PK), Site 1 (SITE_1), Site 2 (SITE_2), Site 3 (SITE_3), St. Lucie Inlet Northeast (SLI_NE), St. Lucie Inlet Southeast (SLI_SE), and Willoughby Creek (WILL_CR).]

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Results and Discussion

Daily rainfall ranged from 0.0 to 2.8 inches per day (in/day) during WY2010–WY2012 and was generally less than 1.0 in/day except for several peaks greater than 2.0 in/day (e.g., January 2010, April 2010, April 2011, November 2011, and January 2012) (**Figure 10-4**). Annual rainfall in WY2012 was close to the long-term average in both the wet and dry seasons (**Table 10-1**). Annual rainfall in WY2010 was above the long-term average due to enhanced dry season rainfall. By contrast, WY2011 rainfall was below the long-term average due to reduced rainfall in both the wet and dry seasons. Rainfall in WY2010 and WY2011 were indicative of the El Niño (WY2010) and La Niña (WY2012) climatic conditions that prevailed. While dry season rainfall during an El Niño tends to be greater than average, rainfall during a La Niña often can be much less (Childers et al., 2006; Abtew and Trimble, 2010).

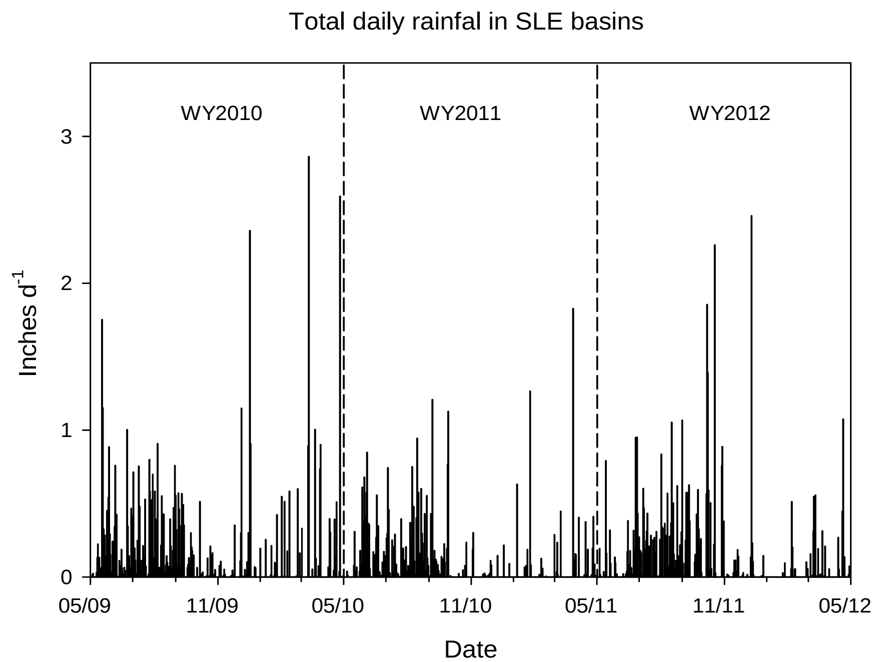

Figure 10-4. Time series of total daily rainfall in inches per day (in/day or inches d^{-1}) to the St. Lucie River Watershed for Water Year 2010 (WY2010) (May 1, 2009–April 30, 2010) through WY2012.

Table 10-1. Total rainfall in inches per day (in/day) to the St. Lucie River Watershed categorized by water year and season. The long-term average is provided relative to Water Year 2010 (WY2010) (May 1, 2009–April 30, 2010), WY2011, and WY2012. The long-term average period of record (POR) is WY1997–WY2012.

POR	Rainfall (in/day)		
	Dry	Wet	Total
WY1997–WY2012 Average	12.1	34.8	46.9
WY2010	21.6	34.3	55.9
WY2011	8.8	25.3	34.1
WY2012	10.0	35.2	45.2

Freshwater inflows to the SLE during WY2010–WY2012 reflected both fluctuations in hydrologic conditions in the watershed and management of releases from Lake Okeechobee. Total daily inflows from the three gauged structures to the SLE were generally less than 2,000 cfs with only a few peaks that approached 4,000 cfs during WY2010–WY2012 (**Figure 10-5**). Annual freshwater inflow was below the long-term average in all three water years (**Table 10-2**). Outflow from Lake Okeechobee was appreciable only in WY2011 with discharges greater than 1,000 cfs from May to October 2010. No further discharges from Lake Okeechobee occurred in WY2011 or WY2012 (**Figure 10-5**).

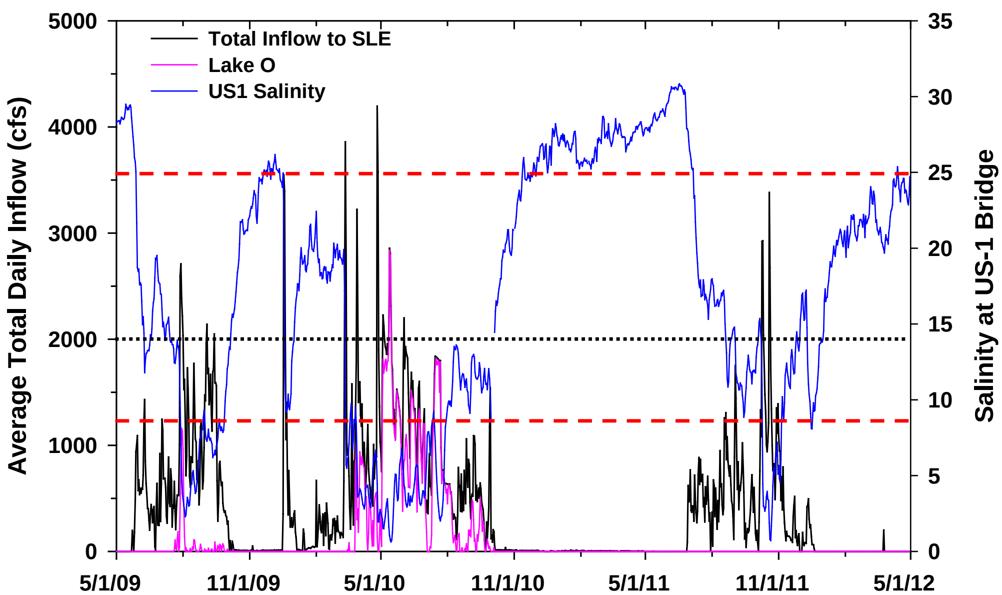

Figure 10-5. Time series of average daily outflow in cubic feet per second (cfs) from three structures (S-80,S-48,and S-49) (black) and from Lake Okeechobee (pink) to the SLE and salinity at the US 1 Bridge (blue) for WY2010-WY2012. The black dashed line represents critical flow of 2,000 cfs. Red dashed lines mark the salinity envelope in the middle of SLE from 8 to 25.

Table 10-2. Total freshwater inflows in million acre-feet (ac-ft) per year and total nitrogen (TN) and total phosphorus (TP) loads in million tons (mtonnes) per year to the St. Lucie Estuary (SLE) from three structures (S-80, S-48, and S-49) and Lake Okeechobee for the long-term average for WY1996–WY2012, WY2010, WY2011, and WY2012.

Water Year	Total Inflow (million ac-ft)	Outflow from Lake Okeechobee (million ac-ft)	Total TP Load (mtonnes)	TP Load Lake Okeechobee (mtonnes)	Total TN Load (mtonnes)	TN Load from Lake Okeechobee (mtonnes)
WY1996–WY2012	0.67	0.28	231.9	55.9	1396.2	602
WY2010	0.41	0.04	144.3	7.6	747.4	80
WY2011	0.31	0.22	69.4	34.6	514.7	357
WY2012	0.20	0.0	82.2	0.0	455.6	0.0

Spatial and temporal fluctuations in salinity are strongly influenced by freshwater inflow (Ji et al., 2007). The inverse relationship between salinity and freshwater inflow is evident in **Figure 10-5**. Salinity is low during the wet season when inflows are high and higher during the dry season when inflows are low. Interannual variation is also apparent. For example, highest salinities were observed during the WY2011 dry season and the beginning of WY2012. There was essentially no inflow from the major water control structures during this period (**Figure 10-5**). Interannual variation is also apparent in the relationship between freshwater inflow and salinity (**Figure 10-6**). The relationships in WY2010 and WY2012 were nearly identical. Given the same freshwater inflow, resulting salinities were lower in WY2011 than in the other two years. For example, maintenance of a salinity of 15 at the US 1 Bridge required an average monthly inflow of approximately 600 cfs in WY2010 and WY2012. By comparison, less than 500 cfs was needed to reach the same salinity in WY2011. The cause of these differences is unknown.

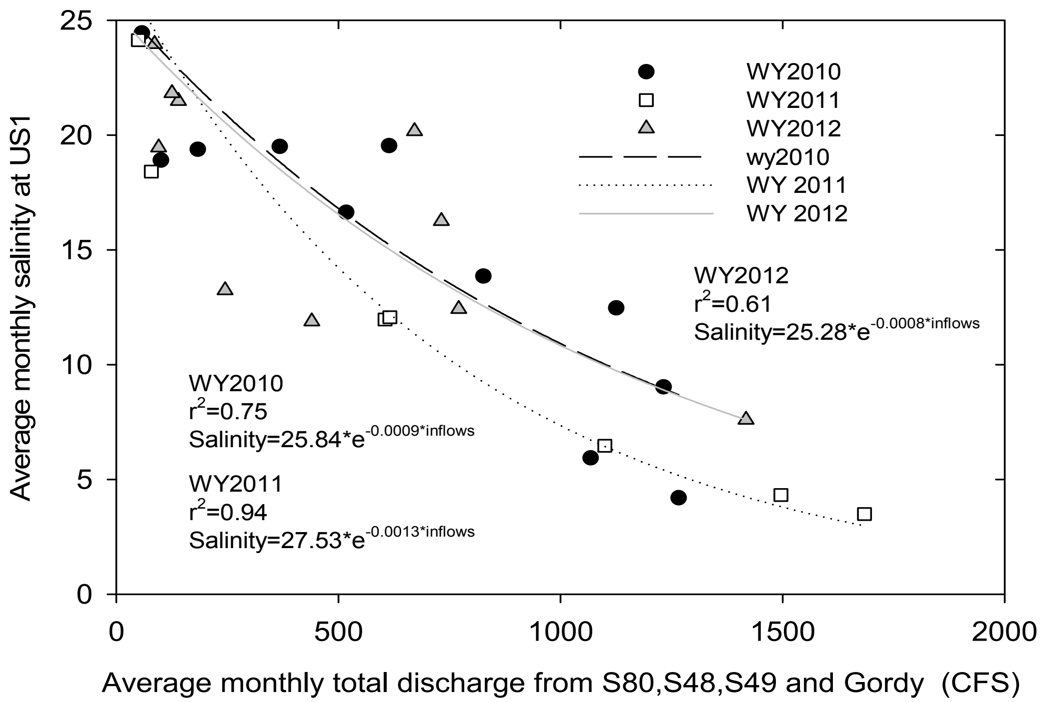

Figure 10-6. Relationships between average monthly inflows (cfs) and average monthly salinity observed at the US1 Bridge station in the SLE for WY2010–WY2012.

To better manage inflows to the SLE, a preferred salinity envelope of 8–25 has been established at the US 1 Bridge and is based on the salinity tolerances of the eastern oyster. In an average year, daily salinity is within this envelope for 65 percent of the time (**Table 10-3**). The percentage of days within the envelope was close to this average in WY2010 (63 percent) and WY2012 (74 percent) but during the drier WY2011 this value fell to only 34 percent.

Table 10-3. The percentages of number of days with salinity values at the US 1 Bridge either less than 8 or greater than 25 for WY2010–WY2012 and their long-term average (WY1999–WY2012).

	Salinity at US 1 Bridge		
Water Years	**Days Salinity <8**	**Days Salinity 8 to 25**	**Days Salinity >25**
WY1999–WY2012	27.4%	65.2%	7.4%
WY2010	24.4%	63.0%	12.6%
WY2011	23.0%	34.5%	42.5%
WY2012	7.1%	74.3%	18.6%

While nutrient loading to the SLE is driven by freshwater inflow (SFWMD et al., 2009a), it is also influenced by discharge from Lake Okeechobee, which accounts for about 43 percent of the total TN load and 24 percent of the total TP load (**Table 10-2**). The annual loading of TN and TP reflected the pattern of total freshwater inflow with reduced inputs in both TN and TP loads for last three years (**Table 10-2**). The lower than average loads in WY2010 and WY2012 also reflected the reduced contribution from Lake Okeechobee, while the relatively low loads in WY2011 reflected the prevailing dry conditions and reduced load from the St. Lucie River Watershed.

TN concentrations at all stations exhibited a seasonal pattern from WY2010 through WY2012 with greater relative concentrations from August to October during each wet season (**Figure 10-7**). TN at stations HR1 and SE03 fluctuated seasonally from 0.5 to 1.5 mg/L as concentrations ranged from 0.1 to 0.7 mg/L at station SE11. The overall magnitude and degree of seasonality were suppressed at SE11 compared to the more upstream stations through reduced freshwater inflow and more oceanic influence at this station close to the St. Lucie Inlet during the POR. Concentrations at all three stations were often below the interquartile range, particularly in WY2011. Annual and long-term average TN concentrations exceeded the TMDL target of 0.72 mg/L at HR1 and SE03, but were similar to this reference value at SE11 (**Table 10-4**).

Table 10-4. Annual and long-term mean concentrations of chlorophyll *a* (Chl*a*) in micgrograms per liter (µg/L), TN in milligrams per liter (mg/L) and TP (mg/L) at three water quality monitoring stations in the SLE.

	Concentrations at SLE Stations								
	HR1			**SE03**			**SE11**		
	Chl*a* (µg/L)	**TN (mg/L)**	**TP (mg/L)**	**Chl*a* (µg/L)**	**TN (mg/L)**	**TP (mg/L)**	**Chl*a* (µg/L)**	**TN (mg/L)**	**TP (mg/L)**
WY1998–WY2009	11.8	1.02	0.222	9.2	1.02	0.196	3.8	0.65	0.076
WY2010	17.3	0.98	0.225	14.8	0.98	0.186	2.5	0.18	0.027
WY2011	11.6	0.73	0.134	6.2	0.75	0.124	3.9	0.31	0.036
WY2012	12.8	0.88	0.197	5.1	0.85	0.181	2.7	0.43	0.053

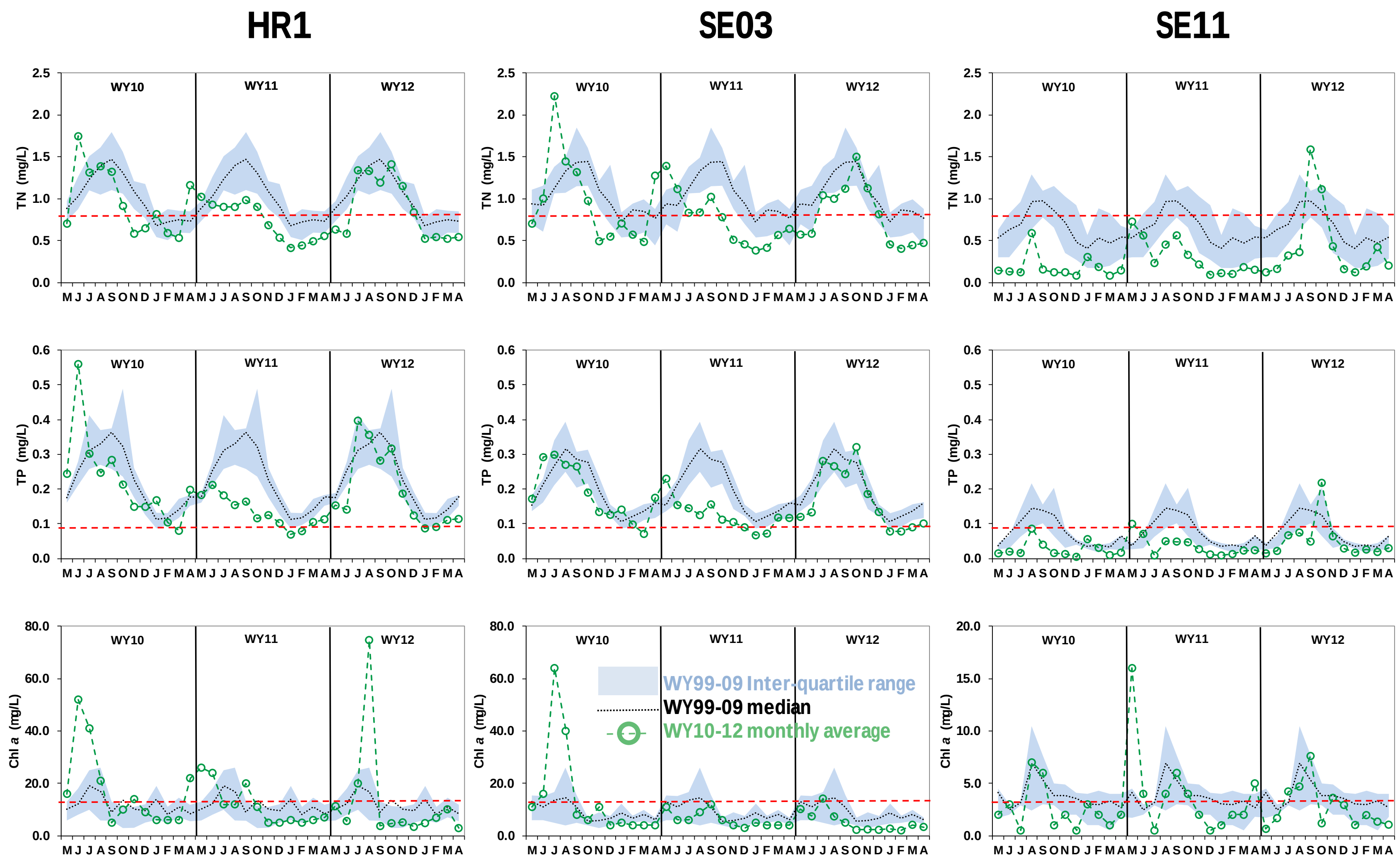

Figure 10-7. Water column concentrations of total nitrogen (TN) in milligrams per liter (mg/L), total phosphorus (TP) in mg/L, and chlorophyll *a* (Chl*a*) in micrograms per liter (µg/L) at stations HR1, SE03, and SE11 in the SLE. Red dashed lines indicate target concentrations of TN (0.72 mg/L), TP (0.081 mg/L), and Chl*a* (11.0 µg/L) related to Total Maximum Daily Loads (TMDLs) to the SLE. Note scale for Chl*a* at station SE11 is only 0–20 µg/L compared to 0–80 µg/L at stations HR1 and SE03.

Similar to TN, TP concentrations exhibited seasonality with greater wet season than dry season values over the POR (**Figure 10-7**). TP concentrations generally were less than the long-term medians at all three stations with the exception of one spike at SE11 towards the end of the WY2012 wet season (**Table 10-4**). Despite reduced TP loading to and concentrations in the SLE from WY2010–WY2011, the annual and long-term mean concentrations were elevated relative to the TMDL target of 0.081 mg/L at both HR1 and SE03. The overall magnitude and degree of seasonality were suppressed at SE11 compared to the more upstream stations through reduced freshwater inflow and more oceanic influence at this station close to St. Lucie Inlet during the POR.

Water column Chl*a* followed a similar temporal pattern as TN and TP at stations HR1, SE03, and SE11 (**Figure 10-7**). While Chl*a* concentrations for the past three water years overall were less than the long-term median, there were obvious peaks of 55 µg/L in May 2009 at HR1, 78 µg/L in July 2011 at HR1, and 65 µg/L in June 2009 at SE03. Long-term and annual mean concentrations of Chl*a* were generally lower than the IWR value of 11.0 µg/L with the exception of station HR1 in the North Fork, where they were consistently higher (**Table 10-4**).

Live oyster densities exhibited temporal and spatial variations with seasonal fluctuations in salinity from WY2010–WY2012 (**Figure 10-8, top panel**). Salinity conditions indicative of drought during each successive dry season were favorable for oyster abundances observed each May, particularly in WY2012. In fact, oyster densities in the SLE appeared to increase over the past three years. Average annual oyster densities were generally greatest at the middle estuary sampling sites compared to the sites in the North and South Forks. While average values ranged from 300 to 650 oysters per square meter ($/m^2$) in the middle estuary, averages in the North Fork and South Fork ranged only from 10 to 100 oysters/m^2. Oyster CI exhibited variability among the three estuarine segments in the WY2010 wet season and into WY2011 (**Figure 10-8, bottom panel**). However, monthly average CI for the three SLE segments were similar starting in August 2010 and remained similar to date. However, CI appears to have decreased at all sites to less than 2.0 grams dry weight oysters per grams dry weight shell (gdw oyster/gdw shell) over the POR. This decline may be related to a higher intensity of infection with the parasite *Perkinsus marinus* resulting from higher salinities in recent years, particularly during WY2011.

Landscape-scale drought over the past three water years was also apparent in patterns of seagrass community composition as salt tolerant species proliferated at meadow sampling sites in the lower SLE and the SIRL (**Figure 10-9**). Six seagrass species were documented at the eight sites from WY2010 to WY2012. SAV species in the lower estuary near the St. Lucie Inlet and the adjacent SIRL included shoal grass (*Halodule wrightii*), manatee grass (*Syringodium filiforme*), turtle grass (*Thalassia testudinum*), Johnson’s seagrass (*Halophila johnsonii*), paddle grass (*Halophila decipiens*), and star grass (*Halophila engelmanni*). High and relatively stable salinities were experienced at the seagrass sites north (mean is 33; range is 26–38) and south (mean is 32; range is 24–38) of the inlet. Lower and more variable salinity was experienced at the Willoughby Creek (WILL_CR) site in the St. Lucie River (mean is 29; range is 4.3–36).

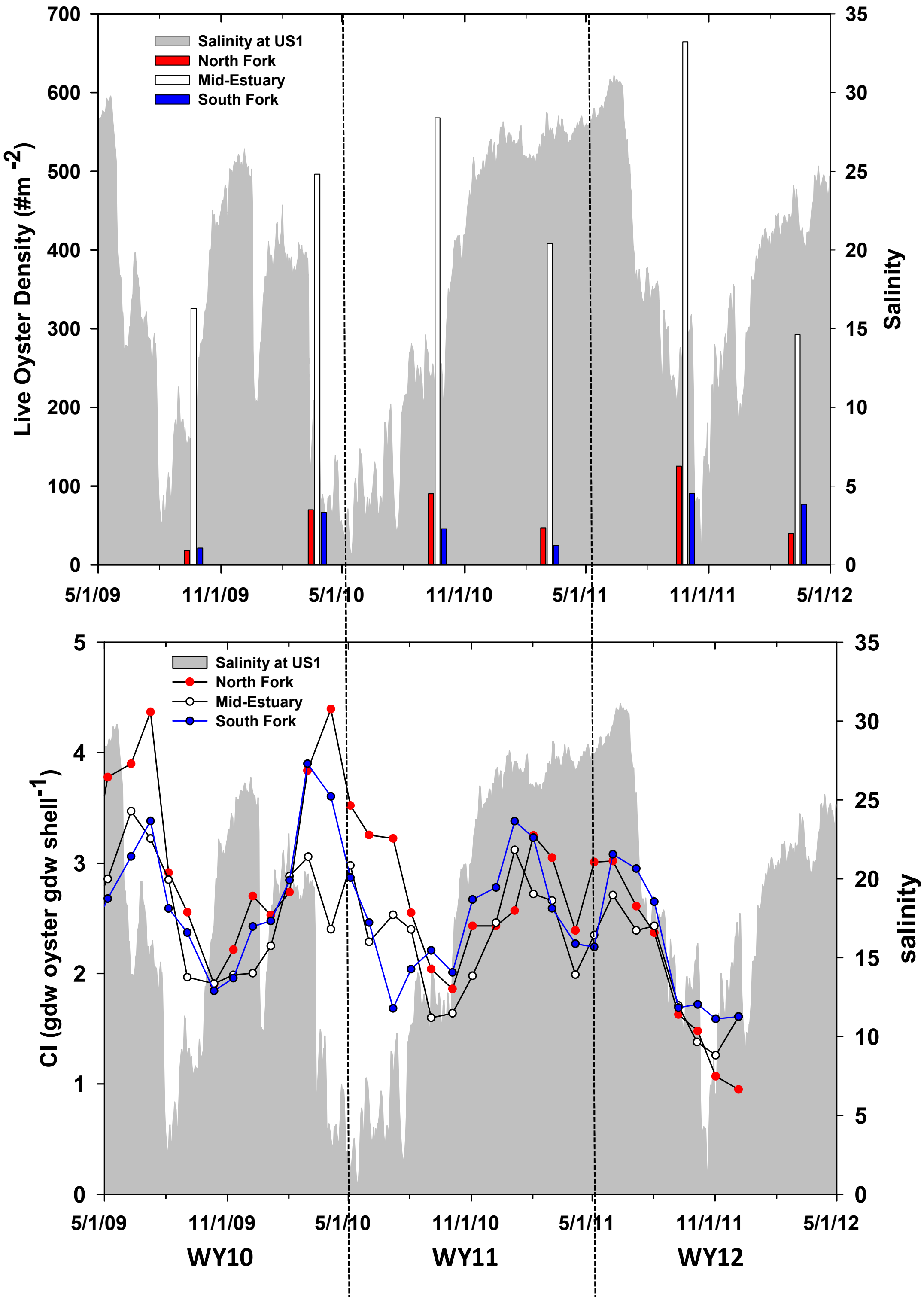

Figure 10-8. Seasonal averages ± standard deviations of live oyster densities in the North Fork, middle estuary, and South Fork of the SLE from WY2010–WY2012 (top panel) and monthly average condition index (CI) in grams dry weight oyster per grams dry weight shell (gdw oysters/gdw shell or g oyster g shell^{-1}) in each of the three estuarine segments.

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The high salinity tolerant shoal grass was the dominant species at the Joe's Point site to the north of St. Lucie Inlet occurring in 60–100 percent of grid observations (**Figure 10-9**). Another seagrass that prefers near ocean salinity, manatee grass, varied from 0 to 60 percent at this location. These two species also were favored at the other northern site (Ocean Breeze Park) along with a declining percentage of Johnson's grass as salinity was elevated and stable throughout the POR. The relative contribution of manatee grass increased while shoal grass decreased in occurrence at Site 1 and Boy Scout Island. The St. Lucie Inlet Northeast site featured a high coverage of shoal grass (greater than 90 percent) but much smaller values for turtle grass (less than 20 percent) and Johnson's grass (less than 5 percent) (**Figure 10-9**). Both shoal and Johnson's grass occurred at the St. Lucie Inlet Southeast site, although the contribution of Johnson's declined to approximately 50 percent by the end of WY2012. These two species were also present at Site 3 along with small percentages (less than 10 percent) of turtle and manatee grasses. The Willoughby Creek site is of particular interest since it is inside the SLE. There were relatively high occurrences of greater than 80 percent for both shoal grass and Johnson's grass from May 2010 to May 2011 (WY2011) before percentages dropped in August 2011 when salinity in the SLE decreased to less than 20; however, Johnson's seagrass returned to greater than 90 percent at the end of WY2012.

Significant Findings

- Rainfall varied both seasonally and annually from WY2010 through WY2012. A wetter than average dry season occurred in WY2010. WY2011 was drier than average in both the wet and dry seasons. Seasonal rainfall in WY2012 compared favorably with long-term averages.
- The total amount of fresh water entering the SLE was less than the long-term average in all three water years and particularly reduced in WY2012, when there were no discharges from Lake Okeechobee.
- Patterns of reduced rainfall and freshwater input drove salinity increases in the SLE that were very high during the WY2011 dry season and the beginning of WY2012. The 8–25 salinity envelope was maintained for 74 percent of the days in WY2012.
- TN and TP loading was less than the long-term average in all three water years.
- Mean concentrations of TN and TP in the North Fork (HR1) and middle estuary (SE03) were greater than the TMDL targets (TN target is 0.72 mg/L; TP target is 0.081 mg/L), but were much closer to the target at SE11.
- Chl*a* concentrations were generally lower than the IWR value except at station HR1 in the North Fork.
- Oyster densities increased throughout the POR although overall oyster CI was observed to be decreasing by WY2012.
- Overall increasing salinity conditions throughout the POR led to increased distribution and dominance of salt tolerant SAV species (shoal grass and manatee grass) both within the lower estuary near the St. Lucie Inlet and in the SIRL.

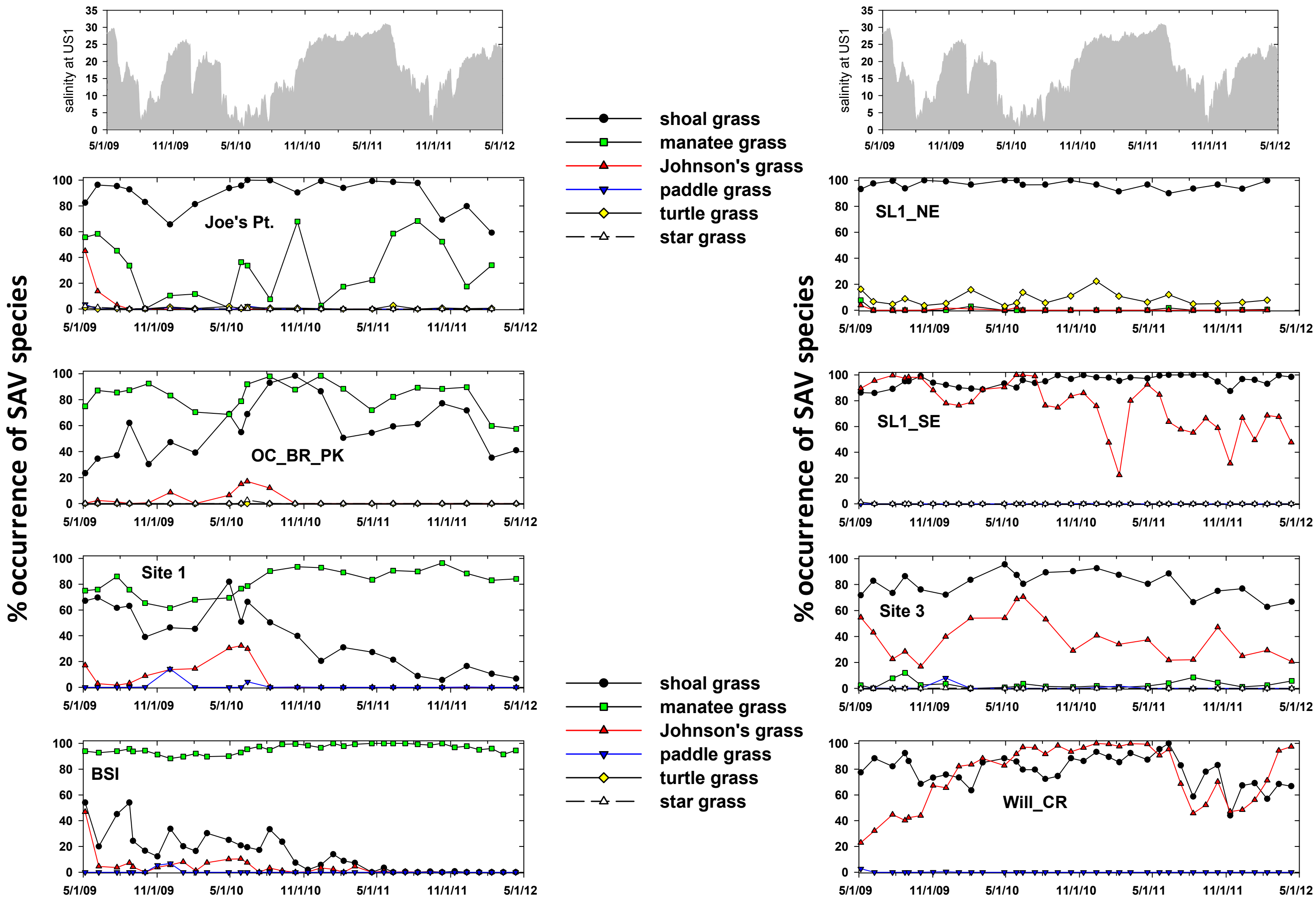

Figure 10-9. SAV community composition at eight stations in the SIRL. The y-axis is the percent occurrence for each of the observed species.

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CALOOSAHATCHEE RIVER ESTUARY HYDROLOGY, WATER QUALITY AND AQUATIC HABITAT

The FDEP has established a TMDL for the CRE. The TMDL technical document was finalized (FDEP, 2009) and the rule was adopted (Chapter 62-304.800, F.A.C.) in 2009. The TMDL focuses on the CRE downstream of the S-79 structure, which encompasses three water body identification areas determined to be impaired for nutrients and dissolved oxygen (DO). The final TMDL for the CRE is 9,086,094 pounds [4,121 metric tons (mt)] per year of TN, which represents a load reduction of 23 percent.

Historically, seagrass meadows and oyster reefs are salient features of the landscape in South Florida estuaries. To evaluate the ecological condition of the CRE, SAV and oysters are routinely monitored. SAV are commonly monitored to gauge the health of estuarine systems (Tomasko et al., 1996) and their environmental requirements can form the basis for water quality goals (Dennison et al., 1993). Oyster beds are a good indicator of estuarine condition as the distribution and abundance of the eastern oyster have ecosystem-scale implications. Oyster beds filter water and suspended solids, couple the water column to the benthos, and provide living aquatic habitat (Peterson et al., 2003; Coen et al., 2007).

Methods

A suite of external drivers and ecological responses are monitored in the Caloosahatchee River Watershed and Estuary. These variables include rainfall, freshwater discharge, and nutrient loading as external drivers, and patterns of estuarine nutrient concentrations, oyster habitat status, and SAV community composition as the ecological responses. Salinity gradients provide a conservative property useful to connect freshwater inflow to estuarine flushing time and biological resource tolerance ranges (Wilbur, 1992; Jassby et al., 1995; Kimmerer, 2002; Hagy and Murrell, 2007; Pollack et al., 2011).

NEXRAD Rainfall data from WY1997 through WY2012 were obtained through the District's DBHYDRO database for 10 distinct NEXRAD units: East Caloosahatchee, West Caloosahatchee, Hicpochee North, Nicodemus Slough South, S-4, Telegraph Swamp, Tidal North, Tidal South, Cape Coral Coastal, and CRE (SFWMD et al., 2012b) (**Figure 10-10**). Total rainfall was calculated using an area-weighted method where the daily rainfall from each basin was scaled by its size relative to the total area of the combined watershed and estuary surface area. Total daily rainfall was derived by summing across all 10 scaled daily unit values and categorized by water year and season to calculate average and total values.

Freshwater discharge is monitored at the major structures along the Caloosahatchee River (C-43 canal): S-77 next to Lake Okeechobee, S-78 near LaBelle, and S-79 at the upstream boundary of the CRE (**Figure 10-10**). Average daily inflow spanning from WY1996–WY2012 for S-77 and S-79 were used to evaluate intra- and interannual variations in overall inflow and to quantify total inflow to the CRE each water year. This included the relative volume contributions from Lake Okeechobee versus contributions from the Caloosahatchee River Watershed. Total daily discharges and contributions were categorized by water year and season. Daily TN and TP loads were calculated using daily inflows at S-79 and S-77 and TN and TP concentrations determined from water samples at the structure. Daily loads from WY1996 through WY2012 were categorized by water year to evaluate temporal variations at different timescales.

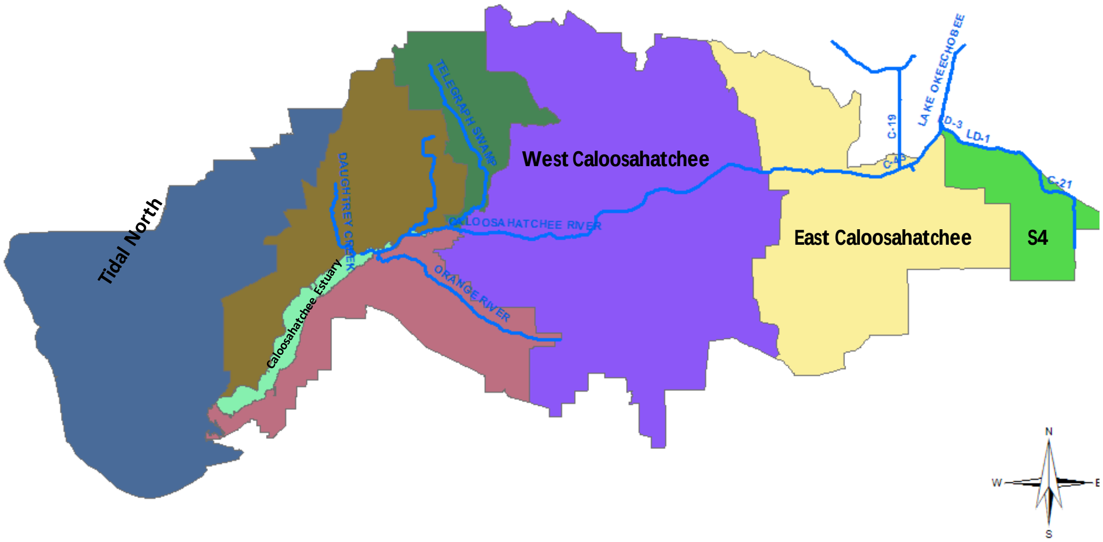

Figure 10-10. Caloosahatchee River Watershed including the S-4, East Caloosahatchee, West Caloosahatchee, Telegraph Swamp, Tidal North, Tidal South, and Cape Coral Coastal basins.

Surface and bottom salinity observations are recorded every 15 minutes at seven stations in the CRE: S-79, Bridge 31, I-75 Bridge (Val I75), Fort Myers, Cape Coral, Shell Point, and Sanibel Island Bridge (**Figure 10-11**). Salinity was evaluated at Fort Myers and the I-75 Bridge where critical criteria have been established. First, daily surface and bottom salinity values were averaged together. Second, the monthly average plus and minus (±) standard deviation of salinity were calculated for each station to produce a time series over the past three water years. Third, salinity data were categorized by water year and season to compare and contrast intra- and interannual patterns. Fourth, an exponential curve was fit to the relationship between average total monthly discharge and average monthly salinity at Fort Myers. The ranges in both values and shapes of the resulting curves were contrasted among WY2010, WY2011, and WY2012

Water quality is sampled at mid-depth at 13 stations in the CRE, San Carlos Bay, and Pine Island Sound at approximately monthly intervals (**Figure 10-11**). Several stations located in the estuary itself were selected to characterize water quality: CES04, CES 06, and CES08. Data for CES01, located in fresh water upstream of S-79, are also shown. Concentrations of TN, TP, and Chl*a* from WY1999 through WY2012 from each of the stations were included in the analyses (SFWMD, 2011). The long-term median value was calculated along with the interquartile range (difference between the 75th and 25th percentiles) to provide an envelope of historical values. Average monthly concentrations from WY2010 through WY2012 were superimposed graphically to contrast patterns among the timescales. Chl*a* concentrations were averaged and compared by water year to a value of 11.0 µg/L from the IWR (Chapter 62-303, F.A.C.).

Figure 10-11. CRE boundaries including structures, water quality stations, and locations of continuous salinity monitoring. The CRE extends from the S-79 water control structure approximately 42 kilometers (km) to the southwest at Sanibel Island and the Gulf of Mexico.

Oyster monitoring has been ongoing at multiple sites in the lower CRE since WY2001 (**Figure 10-12, top panel**). The primary sites for this report are Iona Cove, Kitchell Key, Bird Island, and Tarpon Bay. The CI has been monitored at these sites since WY2001 (Volety et al., 2009; SFWMD et al., 2012b). Live oyster densities have been estimated at each of these sites since WY2005. Live density counts were discontinued at the Tarpon Bay site in WY2012. Time series for average annual CI and live oyster densities were derived for each site over the available POR.

SAV monitoring has been ongoing at multiple sites in the CRE and San Carlos Bay since WY1998. There are seven sites (1, 2, 4, 5, 6, 7, and 8) (**Figure 10-12, bottom panel**) with SAV meadow sizes ranging from 1.0 to 2.0 acres along the length of the CRE from WY2010 through WY2012. A large quadrant grid (3 m x 3 m = 9 m^2) subdivided into 25 equal sub-quadrants was deployed at randomly selected locations within each of the seven sites. The percent occurrence for each seagrass species within each large quadrant grid is determined by the percentage of total sub-quadrants containing each species. The average and standard error of percent occurrence for each species was calculated from the 30 locations at each monitoring site.

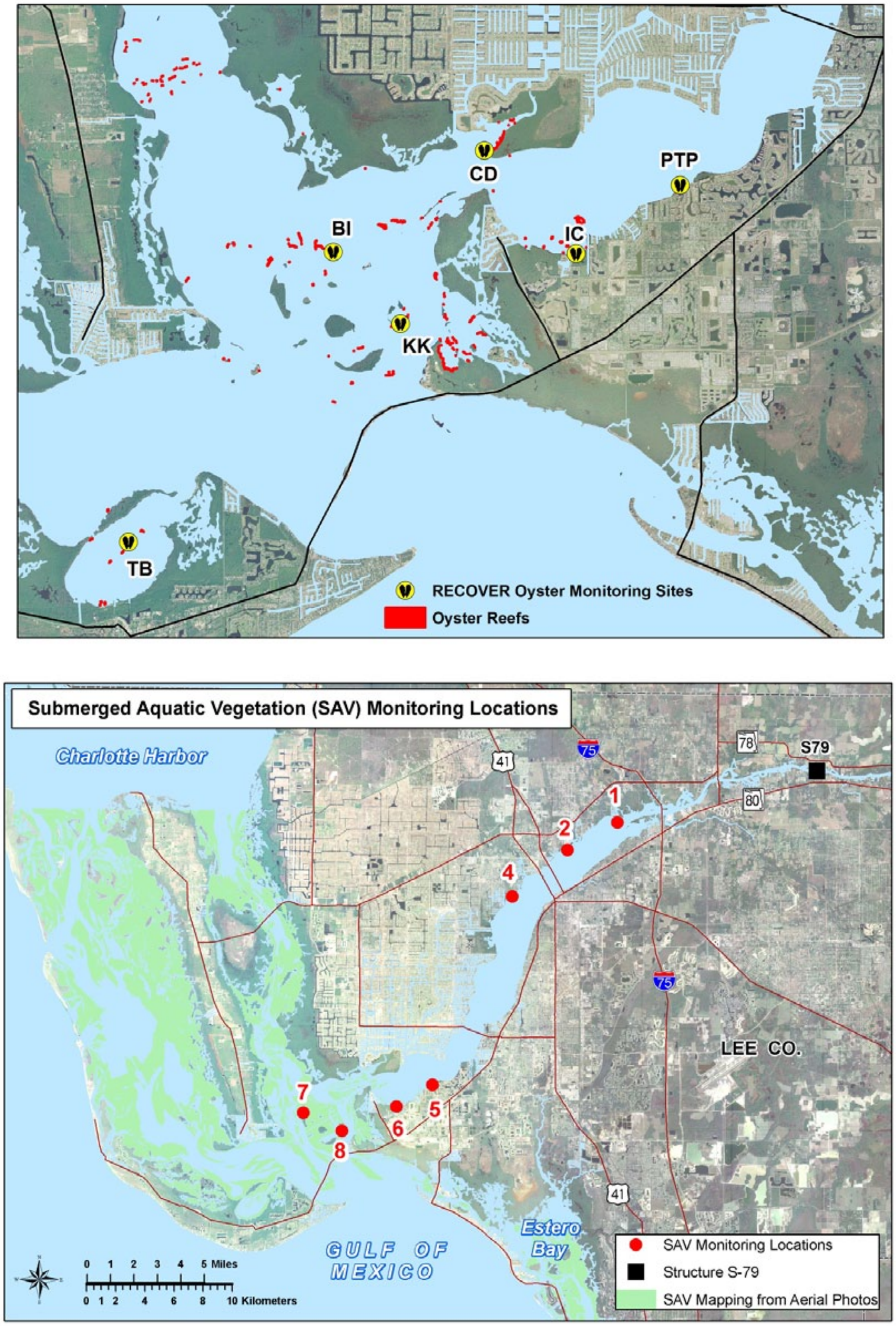

Figure 10-12. Locations for oyster monitoring locations (top panel), and SAV (bottom panel) in the CRE. [Key to stations discussed in this chapter: Bird Island (BI), Iona Cove (IC), Kitchell Key (KK), and Tarpon Bay (TB).]

Results and Discussion

Daily rainfall ranged from 0.0 to 3.3 in/day from May 2009 to April 2012 (**Figure 10-13**). Rainfall amounts were generally less than 1.5 in/day throughout the POR except for peaks greater than 2.0 in/d[1] in April–May 2010 and October 2011. Total annual rainfall during the three water years ranged from a low of 44.3 inches in WY2011, to a high of 64.3 inches in WY2010 (**Table 10-5**). Rainfall in WY2012 (50.5 inches) was very close to the long-term average of about 51 inches. The distribution of rainfall between the two seasons also varied. Wet season rainfall for WY2010 and WY2012 compared well with the long-term average (40.3 inches). The relatively low total rainfall in WY2011 was due to a lower than average wet season rainfall of just 33.7 inches (**Table 10-5**). The relatively higher total rainfall in WY2010 was due to higher than average dry season rainfall of 22.4 inches to the Caloosahatchee River Watershed. This enhanced dry season rainfall is typical of the El Niño conditions that prevailed during this time (Childers et al., 2006; Abtew and Trimble, 2010). By contrast, rainfall during the WY2012 dry season was well below the long-term average.

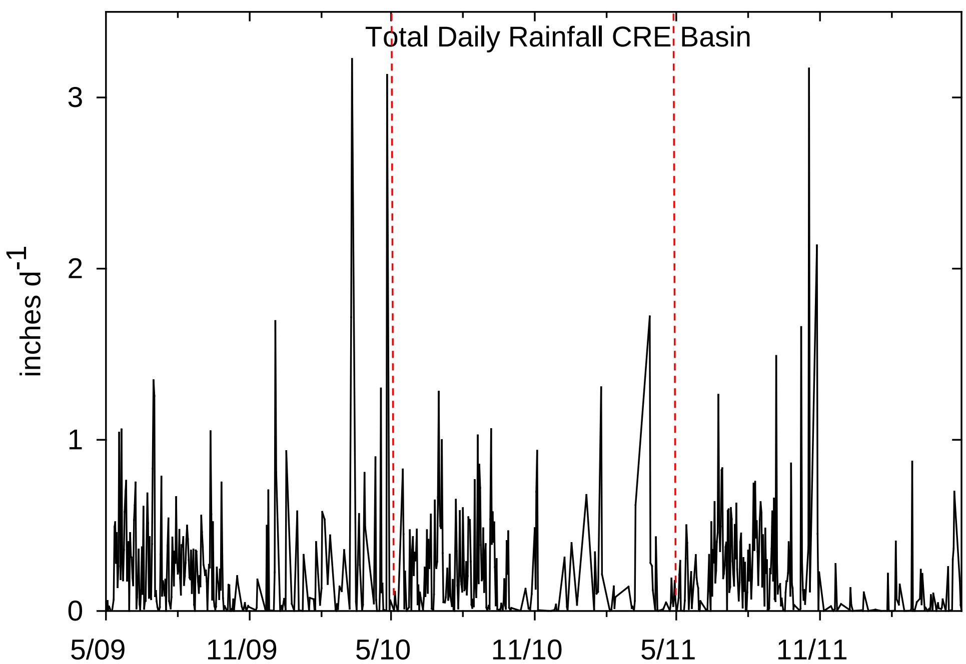

Figure 10-13. Time series of total daily rainfall to the Caloosahatchee River Watershed for WY2010–WY2012.

Table 10-5. Total rainfall to the Caloosahatchee River Watershed categorized by water year and season. The long-term average (WY1997–WY2012) is provided relative to WY2010, WY2011, and WY2012.

POR	Rainfall (in/day)		
	Dry	Wet	Total
WY1997–WY2012 Average	10.8	40.3	51.1
WY2010	22.4	41.9	64.3
WY2011	10.6	33.7	44.3
WY2012	5.9	44.6	50.5

While total discharge at S-79 was lower than the long-term average in all three water years, discharge in WY2012 was lower than the two previous water years (**Table 10-6**). In WY2010, both wet and dry season flows were greater than in WY2012. The difference between WY2011 and WY2012 was due to lower wet season flows in WY2012. Freshwater discharge at S-79 (**Figure 10-14**) represents the combined contribution of rainfall driven runoff from the Caloosahatchee River Watershed and releases from Lake Okeechobee. Over the long-term, slightly over 40 percent of the discharge is from Lake Okeechobee and slightly less than 60 percent is from the Caloosahatchee River Watershed, but there is considerable variability from year to year (**Table 10-6**). For example, total discharge at S-79 was about 1.1 million ac-ft in both WY2010 and WY2011. In WY2010, 63 percent of the discharge occurred during the wet season with 61 percent from the watershed and only 2 percent from the lake. In WY2011, 92 percent of the inflow occurred during the wet season with 52 percent from the watershed and 40 percent from the lake.

Table 10-6. Total inflow in million ac-ft per year to the CRE categorized by contribution of Lake Okeechobee relative to the Caloosahatchee River Watershed for the long-term average (WY1996–WY2012) relative to WY2010, WY2011, and WY2012. The number in parentheses is the percentage of total.

	Inflow (million ac-ft)				
	Lake Okeechobee		Caloosahatchee River Watershed		Total
	Wet	Dry	Wet	Dry	
WY1996–2012 Average	0.31 (21%)	0.31 (21%)	0.68 (47%)	0.15 (11%)	1.5
WY2010	0.02 (2%)	0.12 (11%)	0.67 (61%)	0.27 (25%)	1.1
WY2011	0.45 (40%)	0.05 (5%)	0.59 (52%)	0.04 (4%)	1.1
WY2012	0 (0%)	0.09 (15%)	0.43 (47%)	0.08 (14%)	0.6

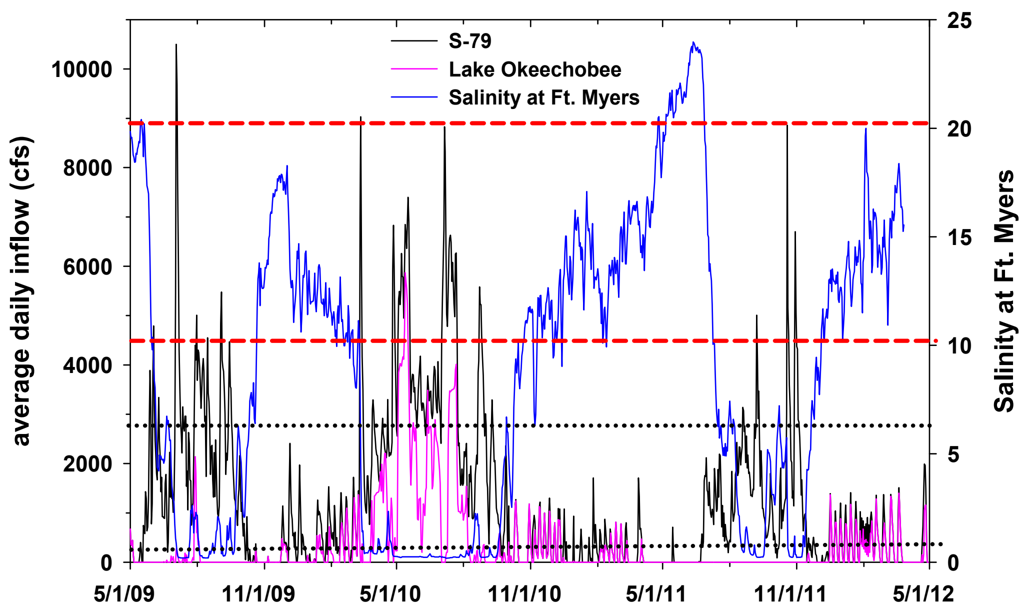

Figure 10-14. Time series of average daily outflow from Lake Okeechobee at S-77 (pink), average daily inflow to the CRE at S-79 (black), and salinity at Fort Myers (blue). The black dashed line represents the critical flow envelope of 300–2,800 cfs. Red dashed lines mark the salinity envelope in the CRE from 10 to 20.

The observed temporal variations in salinity at the Fort Myers station from WY2010–WY2012 exhibited the expected seasonal pattern that is inversely related to freshwater inflow. Salinity increases when inflows are low during the dry season and decreases during the wet season when freshwater inflows increase (**Figure 10-14**). Annual peak dry season salinities at Fort Myers reflect dry season inflows, being lowest in WY2010 when dry season flows were highest and highest in WY2011 when dry season inflows were lowest (**Figure 10-14** and **Table 10-6**). The highest salinities recorded at the Fort Myers station peaked at over 20 and occurred during the first two months of WY2012 when there was essentially no discharge at S-79 (**Figure 10-14**).

Exceedances of the critical salinity criteria normally occur in the dry season months during the latter half of the water year. Of the three water years, exceedances of critical salinity criteria in the CRE were lowest in WY2010 when dry season rainfall was highest (**Table 10-7**). WY2012 saw the highest percentage of exceedances for both criteria (**Table 10-7**). This was due not only to exceedances in the WY2012 dry season (November 2011–April 2012) but also to dry conditions during the first two months of WY2012 (May and June 2011) (**Figure 10-14**). In fact, exceedances of the salinity criteria (20) in WY2012 occurred primarily during this two-month period (**Figure 10-14**).

Table 10-7. Exceedances of critical salinity criteria at Fort Myers for WY2010–WY2012. At the Fort Myers station, daily average salinity should not exceed 20 and the 30-day moving average should be below 10. At the Val I75 site, the 30-day moving average should be below 5. The POR for the long-term average for the Fort Myers station is WY1992–WY2012 and Val I75 station is WY2006–WY2012.

POR	Fort Myers		Val I75
	Days with Daily Salinity > 20	Days with 30-day Moving Average Salinity > 10	Days with 30-day Moving Average Salinity > 5
Long-term average	8.00%	35%	44%
WY2010	0.00%	39%	23%
WY2011	1.00%	45%	35%
WY2012	16%	58%	56%

Salinity downstream of S-79 is influenced not only by freshwater discharge at S-79 but also by inflow from the downstream tidal basin. Interannual variation in the exponential relationship between freshwater discharge at S-79 and salinity at Fort Myers in part reflects the varying influence of tidal basin inflows (**Figure 10-15**). For example, maintenance of a salinity of 10 required an average monthly inflow of approximately 800 cfs at S-79 in WY2010 and WY2012, but only 430 cfs in WY2011. Some of this difference may be due to differences in discharge from the tidal basin downstream of S-79 with potentially higher tidal basin flows in WY2011.

Annual nutrient loading at S-79 is highly correlated with annual freshwater inflow (SFWMD, et al. 2009b). The annual loading of TN and TP through S-79 on the Caloosahatchee River were below the long-term average in all three water years (**Table 10-8**). As with freshwater discharge, loading of TN was similar in WY2010 and WY2011. The distribution of the TN load between Lake Okeechobee and the Caloosahatchee River Watershed reflects the annual distribution of discharge. In WY2011, 45 percent of the discharge came from the lake. In WY2010 only 14 percent of the discharge at S-79 came from the lake. The contribution from the lake to the TN load in WY2011 was greater (55 percent) than in WY2010 (14 percent). WY2012 had the lowest discharge and the lowest TN and TP loads (**Table 10-8**).

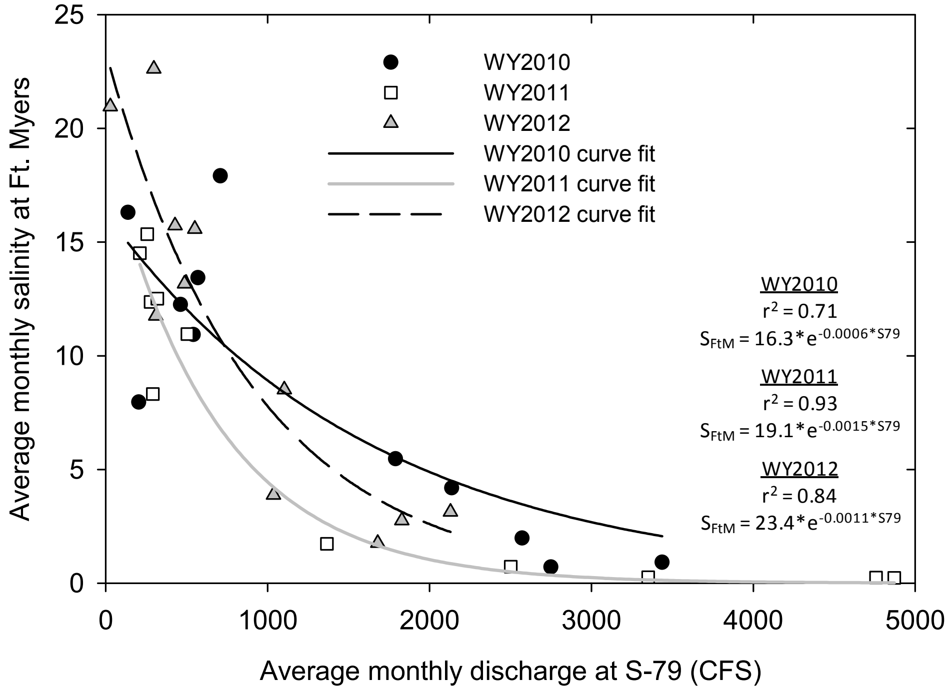

Figure 10-15. Relationship between average monthly inflow and average monthly salinity observed at Fort Myers in the CRE from WY2010–WY2012.

Table 10-8. Total freshwater inflow to the CRE, total outflow from Lake Okeechobee, and the total and contribution of Lake Okeechobee to the TN and TP loading to the estuary for the long-term average (WY1996–WY2012), WY2010, WY2011, and WY2012.

Water Year	Total Inflow to CRE (million ac-ft)	Outflow from Lake Okeechobee (million ac-ft)	Total TP Load (mtonnes)	TP Load from Lake Okeechobee (mtonnes)	Total TN Load (mtonnes)	TN Load from Lake Okeechobee (mtonnes)
WY1996–WY2012	1.5	0.5	232.0	71.3	2,538.1	917.2
WY2010	1.1	0.1	205.9	18.4	1,949.8	270.6
WY2011	1.1	0.5	162.9	63.3	1,869.7	1034.9
WY2012	0.6	0.1	111.5	9.3	1,008.7	158.9

TN concentrations at stations CES01, CES04, CES06, and CES08 did not vary considerably from the long-term trend between WY2010 and WY2012 except for peaks near 3.0 mg/L at CES01 in May 2011 and 5.0 mg/L at CES04 in February 2010 (**Figures 10-16** and **10-17**). Seasonality in TN concentrations was apparent at all stations with greater values in the wet season. Similar to TN, TP concentrations in the CRE were within a relatively narrow range of 0.1–0.2 mg/L and did not vary considerably from the long-term trend except at CES04 during WY2010 (**Figures 10-16** and **10-17**). TP concentrations at CES08 in San Carlos Bay from WY2010–WY2012 were less than the long-term (WY1999–WY2009) interquartile range.

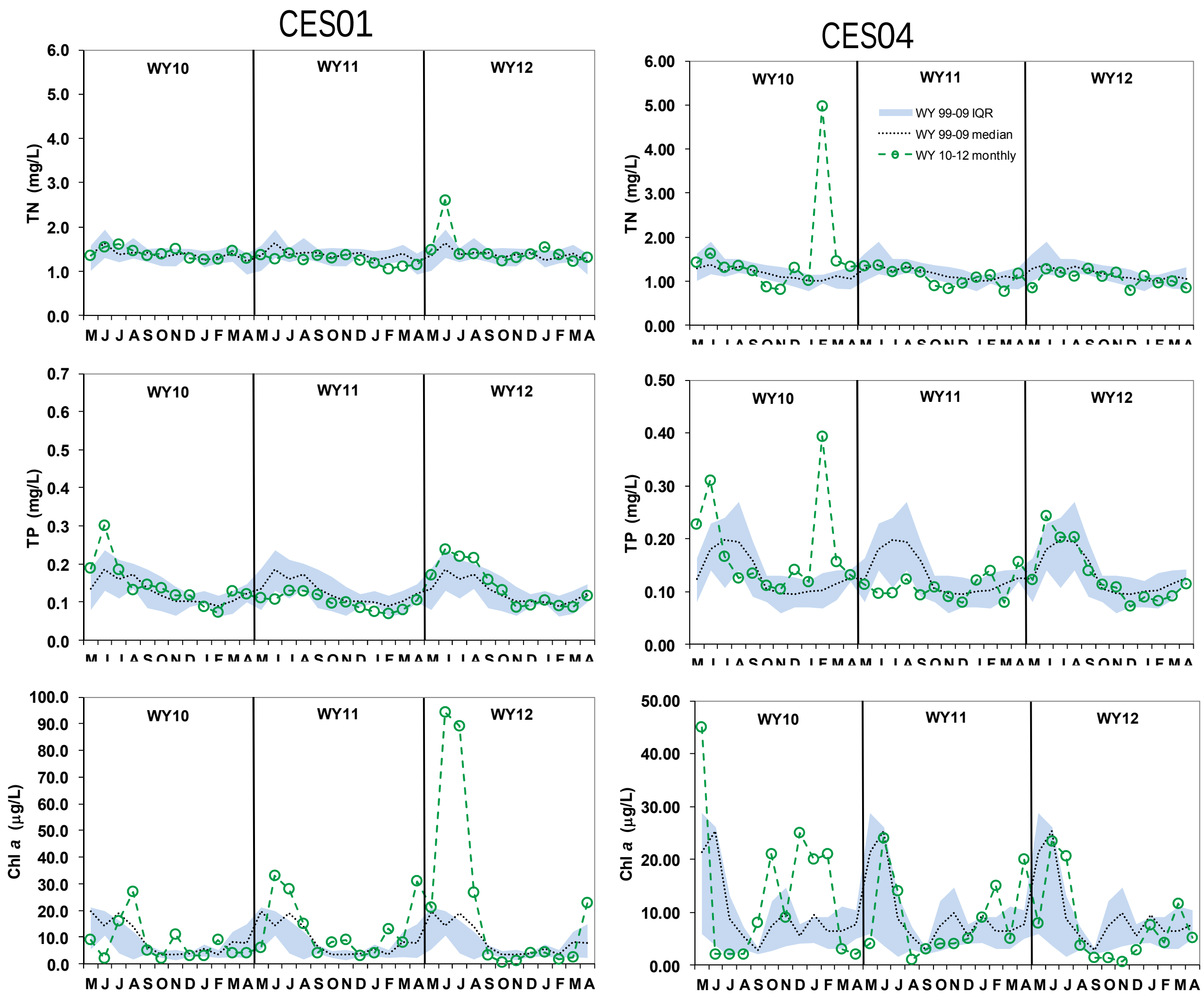

Figure 10-16. Water column concentrations of TN, TP, and Chl*a* at stations CES01 and CES04 in the CRE. The long-term (WY1999-WY2009) inter-quartile range (blue shade) and median (black dash) are provided along with monthly values for WY2010–WY2012. Note that the scale for Chl*a* at CES01 ranges from 0–100 µg/L while the range at CES04, CES06, and CES08 was 0-50 µg/L.

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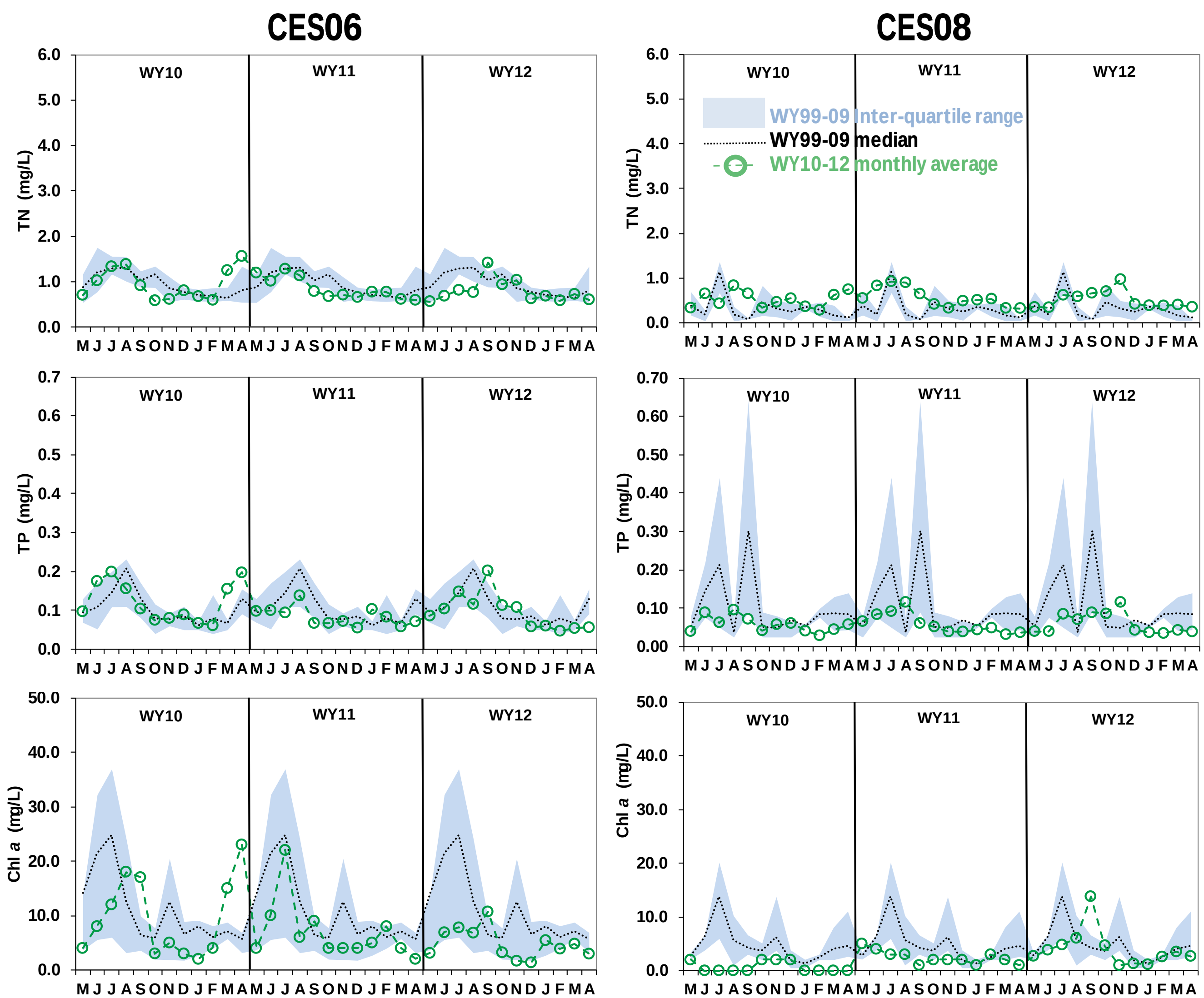

Figure 10-17. Water column concentrations of TN, TP, and Chla stations CES06 and CES08 in the CRE. The long-term (WY1999–WY2009) interquartile range (blue shade) and median (black dash) are provided along with monthly values from WY2010–WY2012.

Water column Chl*a* concentrations ranged from 5 to 30 µg/L at CES01 until May 2011 when concentrations approached 100 µg/L (**Figures 10-16** and **10-17**). Conditions of very low flow (**Figure 10-14**) and water temperature greater than 27.0 degrees Celsius (°C) may have contributed to the observed algal bloom upstream of S-79 in May–June 2011. In WY2012, Chl*a* concentrations were near long-term median values at CES04, CES06, and CES08 (**Table 10-9**). Chl*a* values tended to be higher at the upstream CRE stations, CES04 and CES06, than downstream at CES08. This is consistent with previous observations (Doering et al., 2006). the high annual value in WY2012 was due to the two high concentrations measured in May and June (**Figure 10-16**). In the downstream estuary, annual average Chl*a* exceeded the IWR value of 11 µg/L only at CES04 during WY2010 (**Table 10-9**).

Table 10-9. Average water column Chl*a* concentrations from stations CES04, CES06, and CES08 on the CRE for WY2010–WY2012. Critical concentration is 11 µg/L.

	Chl*a* Concentrations (µg/L)			
	CES01	**CES04**	**CES06**	**CES08**
WY2010	7.9	13.3	9.5	0.7
WY2011	14.8	9.0	6.8	2.4
WY2012	22.6	7.5	4.9	4.0

Live oyster densities exhibited temporal variations with seasonal fluctuations in freshwater inflow and salinity from WY2010 to WY2012 (**Figure 10-18, top panel**). Salinity conditions indicative of reduced freshwater inflow were favorable for oyster abundances throughout the POR, particularly at the Bird Island site. Average values ranged from 1,200 to 3,000 oysters/m^2 at this location with maxima observed in July 2010 and July 2012. Live densities ranged from approximately 500 to 3,000 oysters/m^2 across the four sites with overall reduced densities in the WY2012 wet season (July 2011). These reduced densities may have resulted from the high salinities experienced during the previous WY2011 dry season. High salinity accompanies an increase in predation rates as well as in the intensity of parasitic infection. Oyster CI exhibited little seasonal or spatial variation (**Figure 10-18, bottom panel**). At both the Kitchell Key and Bird Island sites, highest values occurred in June 2010 and June 2011. Oysters from the Bird Island site with the greatest abundance had the lowest CI values less than 2.0 gdw oyster/gdw shell.

SAV community composition in the CRE varies following longitudinal gradients in salinity and light. These gradients vary seasonally depending upon freshwater inflow and the loading of particulate and dissolved materials from the watershed. Upstream Sites 1 and 2 feature a combination of tape grass and widgeon grass (*Ruppia maritima*) (**Figure 10-19**). Tape grass approached almost 80 percent occurrence in WY2011 at Site 1 but was absent in WY2012. The loss of tape grass at this site may be caused by the high salinities (greater than 15) that occurred in the WY2011 dry season. Tape grass and widgeon grass were present at Site 2 at low percentages throughout most of the POR, but an increase in both was evident in WY2011. This is likely due to the lower salinities during the end of WY2010 and the beginning of WY2011. There were occasional occurrences of shoal grass at Site 2 primarily in May during both WY2010 and WY2011. Shoal grass was present at low percentages at Site 4 throughout the POR, but widgeon grass was the primary species and appeared in WY2011 and WY2012 at comparatively high percentages (approximately 80 percent). Shoal grass was the dominant species at Sites 5 and 6, with 80–100 percent occurrence at Site 5, but fluctuating percentages of 10–60 percent at Site 6. Shoal grass and turtle grass were the most abundant SAV species at the polyhaline Sites 7 and 8. Turtle grass, a dominant marine SAV species, exhibited increasing occurrence and dominance since June 2011 (WY2012) at both sites.

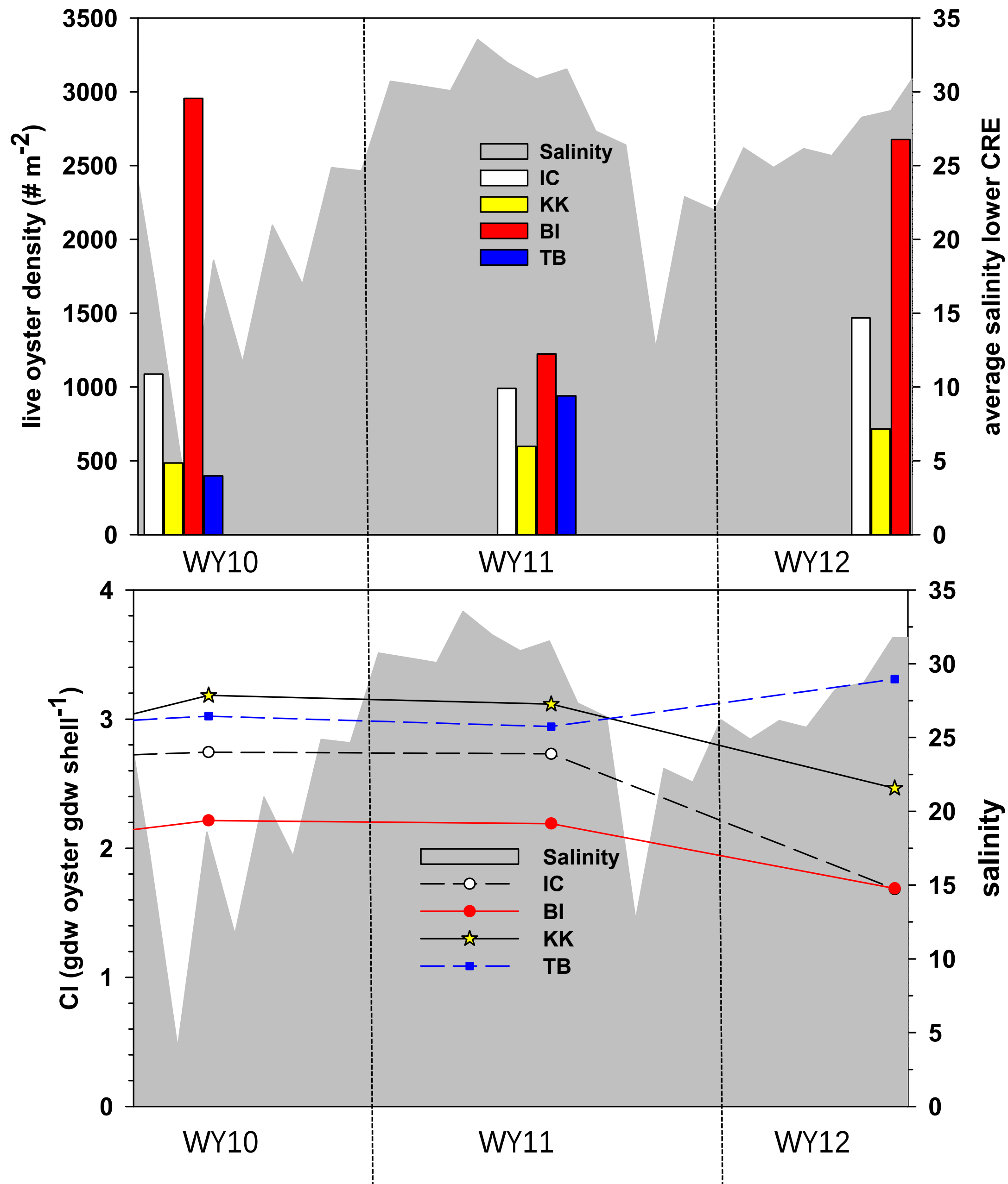

Figure 10-18. Seasonal averages ± standard deviations of live oyster densities in the lower CRE from WY2010 to WY2012 (top panel) and monthly average CI at each of the sites (bottom panel).

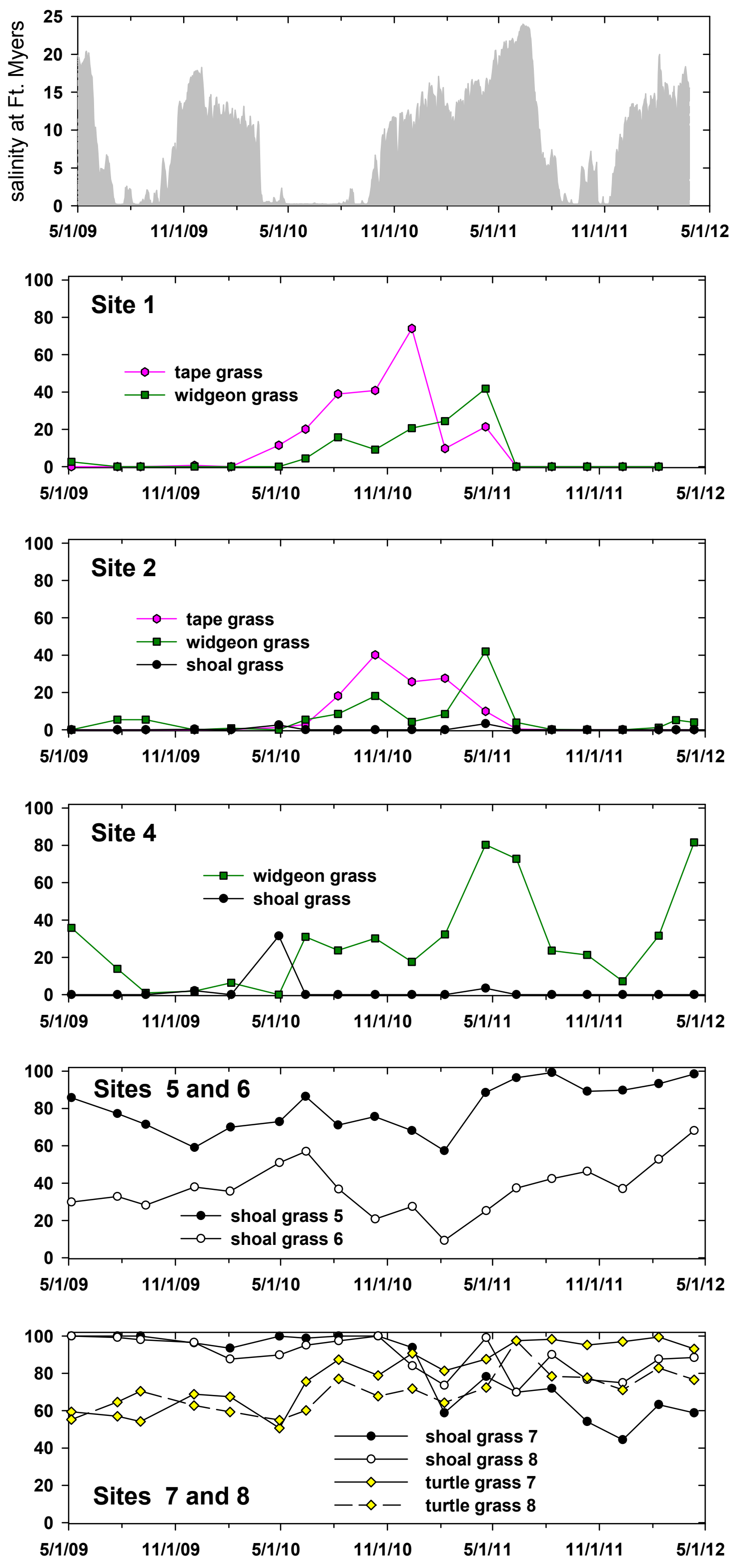

Figure 10-19. SAV community percent composition at seven stations along the length of the CRE. The y-axis is the percent occurrence for each of the observed species.

Significant Findings

- Total annual rainfall during WY2012 was close to the long-term average. Rainfall was lower than average in WY2011, and greater than the average in WY2010. The distribution of rainfall between the two seasons also varied. Wet season rainfall for WY2010 and WY2012 compared well with the long-term average (40.3 inches). The relatively low total rainfall in WY2011 was due to a lower than average wet season rainfall. The relatively higher total rainfall in WY2010 was due to higher than average dry season rainfall that accompanied El Niño conditions. Rainfall during the WY2012 dry season was considerably reduced relative to the long-term average.
- Total discharge at S-79 was lower than the long-term average in all three water years. Discharge in WY2012 was lower than the two previous water years. While total discharge was similar in WY2010 and WY2011 the contribution from Lake Okeechobee was smaller in WY2010 (13 percent) than in WY2011 (45 percent).
- Exceedances of critical salinity criteria in the CRE were lowest during WY2010 when dry season rainfall was highest. Exceedances of both criteria were highest in WY2012, in part due to a lack of discharge at S-79 at the beginning of the water year (May–June 2011).
- TN loading at S-79 was below the long-term average of about 2,500 mt in all three water years. Loading of TP from S-79 was also lower than the long-term average of 232 mt in all three water years.
- All three estuary monitoring sites were below the IWR value of 11 µg/L with the exception of CES04 in WY2010, where the target was exceeded by 2.2 µg/L. A significant algal bloom occurred upstream of S-79 in May–June 2011 (WY2012). This bloom was associated with a period of greatly reduced freshwater inflow and high seasonal temperatures greater than 27 ^{o}C.
- Live densities of oysters ranged from approximately 500–3,000 oysters/m^2 across the four sites with overall reduced densities in the WY2012 wet season (July 2011). These reduced densities may have resulted from the high salinities experienced during the previous WY2011 dry season. High salinity accompanies an increase in predation rates as well as in the intensity of parasitic infection.
- After disappearing from the upper estuary in 2009, tape grass reappeared during WY2011 but was absent in WY2012. The loss of tape grass may be caused by the high salinities (greater than 15) that occurred in the WY2011 dry season and into the WY2012 wet season.

ADAPTIVE PROTOCOL STUDY

Introduction

The AP Study presented a unique opportunity to evaluate the potential effects of different short-term inflow strategies on water quality and plankton abundances during the dry season in the CRE. The AP Study was unique because it combined the operational capacity to regulate Lake Okeechobee inflow through S-79 with hypothesized ecological responses along the CRE salinity gradient and rapid in situ data acquisition (e.g., flow-through system) (Madden and Day, 1992; Doering et al., 2002; Buzzelli et al., 2003; Lane et al., 2007).

Gradients of salinity, nutrient supply, and submarine light penetration regulate the composition and magnitude of biological production in estuaries (Buzzelli et al., in press A). In many estuaries there is an upstream zone of maximum water column production, the LSZ, that serves as a nursery area for many important fish and shellfish (Whitfield, 1994; Kimmerer et al., 2012). Freshwater inflow has a great influence over the early life history and community composition of estuarine fish assemblages throughout the estuary, but particularly in the LSZ (Livingston et al., 1997; Gillson, 2011). Derived through knowledge of estuarine circulation and food webs, a common conceptualization hypothesizes that the following attributes exhibit concentration maximum sequentially in the downstream direction: turbidity, nutrients, phytoplankton, zooplankton and bivalves, and fauna (e.g., birds, crabs, and fish) (Wolanski et al., 2004) (**Figure 10-20A**). The assumption is that freshwater inflow brings the required materials and nutrients to stimulate phytoplankton production just downstream of the turbidity maximum where light is less limiting.

The multiple fates of phytoplankton production are sinking, consumption by zooplankton, and/or downstream transport. Low discharge and long flushing times often result in an overaccumulation of phytoplankton-derived organic matter (Dettmann, 2001; Sheldon and Alber, 2006; Buzzelli, 2011). Because the phyto-detritus is highly labile and easily remineralized in the water column and sediments, overproduction stimulates further algal blooms (Philips et al., 2011). By contrast, rapid flushing removes phytoplankton from the LSZ and potentially the estuary without sinking or biological consumption (Doering et al., 2006; Lucas et al., 2009). Between these extremes exists an optimal range of inflows to promote phytoplankton production, zooplankton growth and consumption, and trophic transfer to larval and juvenile fishes (Kimmerer, 2002; Lucas et al., 2009). It is important to note that increased rates of primary production may not manifest as increased biomass (e.g., Chl*a* concentration) because predation rates by zooplankton and filter feeders also increases (**Figure 10-20B**).

The conceptual model also accounts for potential temporal differences in estuarine structure at different timescales (**Figure 10-20A**). It is reasonable to assume that the extent and longitudinal position of the LSZ and the offshore plume could vary on both synoptic (3–5 days) and seasonal (dry versus wet) scales. While the first two-thirds of this chapter assessed patterns at the seasonal and water year scales, the AP Study was conducted at the scale of both Lake Okeechobee operations and planktonic responses in the LSZ. The conceptual model suggests that short-term, freshwater pulses could enhance planktonic production in different parts of an estuary depending upon pulse magnitude and duration. Therefore, the AP Study focused on the synoptic timescale to assess potential effects of short-term pulses of Lake Okeechobee derived fresh water on water column ecological attributes along the length of the CRE.

The AP Study introduced pulses of fresh water and tracked estuarine patterns downstream of S-79 in the CRE. Seven individual intensive research cruises occurred from January to April 2012. The cruises coincided with controlled freshwater releases and utilized a combination of continuous flow-through technology and a series of vertical sampling stations.

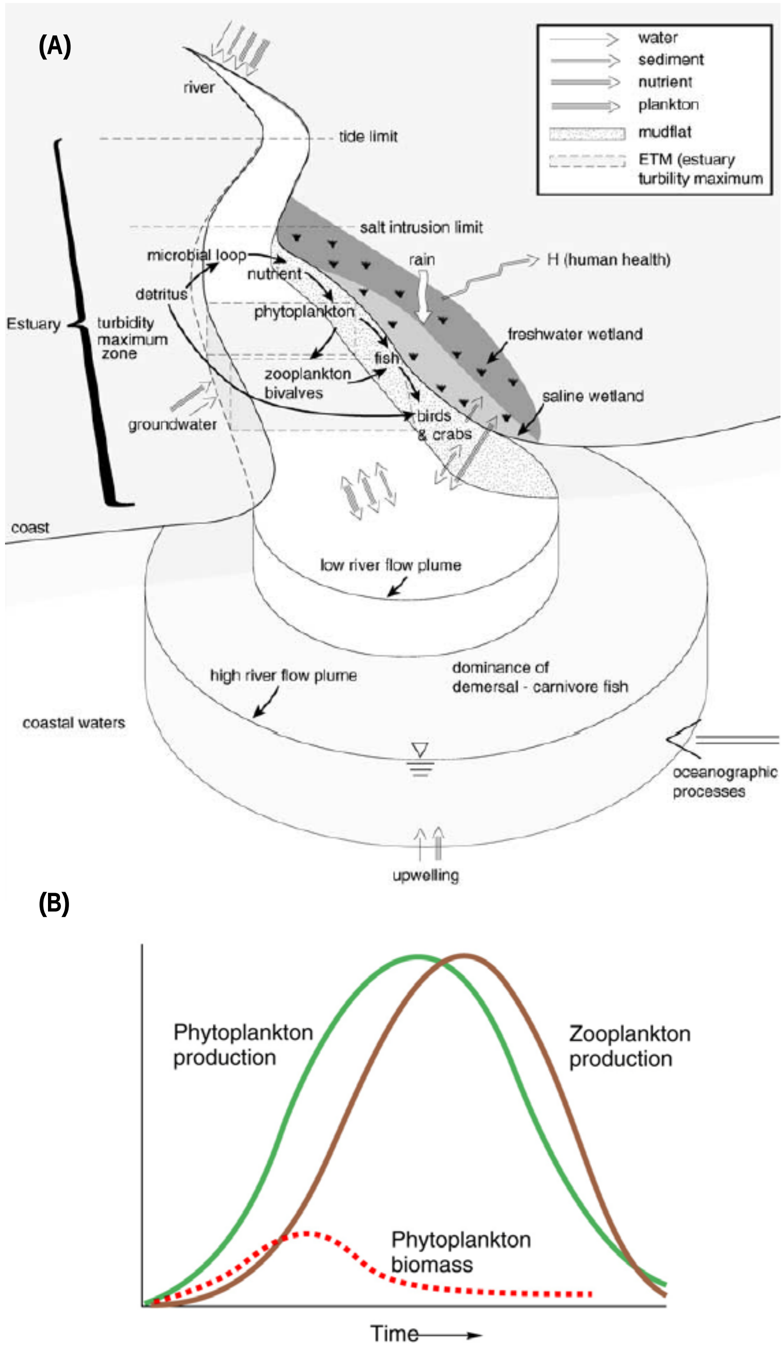

Figure 10-20. (A) Conceptual model of estuarine plume physical and biogeochemical structure. The extent of the estuary between river upstream and the offshore plume depends upon the magnitude of freshwater inflow. Low and high river flow plumes can be conceptualized on timescales ranging from days (synoptic weather fronts and management operations) to years (interannual variations in climate). The turbidity maximum zone is conceptualized as shifting habitat where materials are rapidly cycled between dissolved inorganic nutrients, phytoplankton, microbes, and zooplankton. (B) Hypothesized relative patterns of phytoplankton production (green), zooplankton production (red), and phytoplankton biomass (red dash) in estuaries.

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Methods

Operations

During the WY2012 dry season, pulse releases from Lake Okeechobee were made to the CRE under the Final Adaptive Protocols for Lake Okeechobee Operations (SFWMD, 2010). Pulse releases with a target average of 450 cfs began on December 16, 2011 when the Lake Okeechobee water level was in the Baseflow sub-band of the 2008 LORS and ceased on March 27, 2012. During the week preceding March 27, 2012, water levels in the lake fell into the Beneficial Use sub-band and the Tributary Hydrologic Conditions fell into the dry category. Under the Adaptive Protocols the latter event precipitated the cessation of pulse release to the CRE.

Three types of pulse releases were made. The first, was a front loaded seven-day pulse with all the flow occurring during the first four days, and no flow occurring over the last three days. Target flows on the first four days were 1,000 cfs, 1,200 cfs, 600 cfs, and 350 cfs. Six of these pulses were conducted (**Figure 10-21**). The second scenario was a two-day oscillating pattern with target flows of 900 cfs on day 1 and no flow on day 2. Releases following this pattern were conducted for 10 days. The third was a 10-day front loaded pulse with flow occurring during the first six days of the pulse and no flow occurring over the final four days. Target flows on the first six days were 1,100 cfs, 1,600 cfs, 850 cfs, 500 cfs, 350 cfs, and 100 cfs.

It is important to consider that the actual magnitude of the daily flows were somewhat different than the targets and varied over the course of the AP Study.

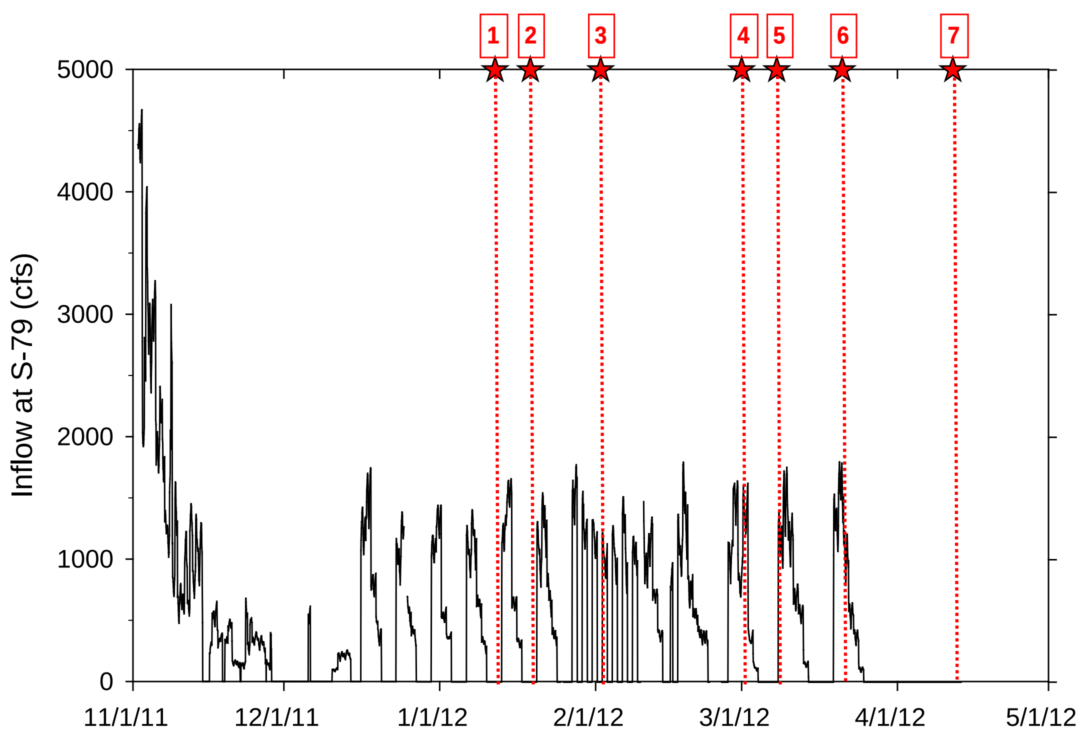
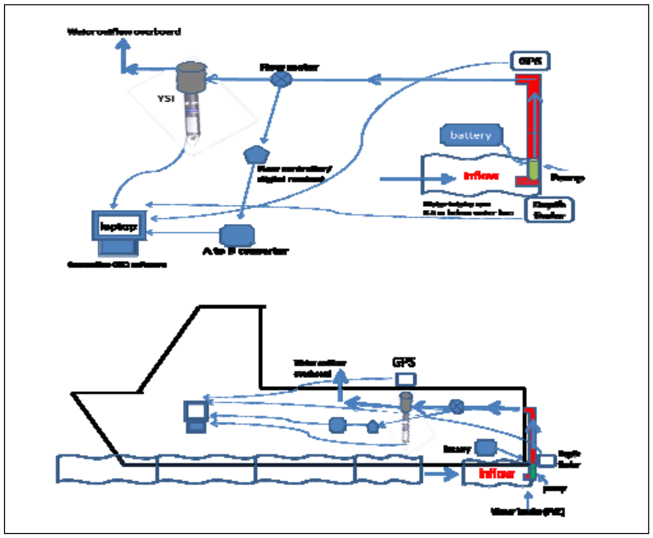


Figure 10-21. Daily freshwater inflow at S-79 from November 1, 2011 to April 20, 2012. There were seven flow-through cruises from January to April 2012 (see **Table 10-10** for cruise details). See *Methods* section text above for S-79 release patterns.

Flow-through system

The flow-through system offers a novel method to acquire in situ surface water data while the research vessel is under way permitting researchers to rapidly sample vast areas of an estuary (Madden and Day, 1992; Lane et al., 2007). The system consists of an intake ram attached to the stern, a flow meter, a Trimble Global Position System (GPS), a YSI 6600 multi-probe instrument, and a bathymetric profiler and laptop computer with Streamline GEO software (**Figure 10-22**).

(A)



(B)

Figure 10-22. (A) Schematic of flow-through system for in situ monitoring of surface water quality. A shipboard battery-pump system brings water through an aft-mounted intake to the boat deck where it passes across a flow meter and onto a YSI multi-probe unit. The entire system is connected to a Global Positioning System (GPS) and onboard lap top computer. (B) Pictures of the YSI multi-probe, battery, flow meter, GPS antenna, water delivery tubing, and the aft-mounted intake.

The YSI 6600 was set up to record temperature, salinity, pH, turbidity, DO, and in situ Chl*a*. The intake ram was at 0.5 m below the water surface with an in-line pump to ensure water flowed through the system when the boat was stopped or at reduced speed. The GPS and YSI recorded data every 5 seconds. Streamline Geo software permitted integration of the GPS and surface water data into an ArcGIS shape file useful both to display surface water properties in real time and in the post-processing of spatial data. Approximately 7–8 hours were required to travel from S-79 to San Carlos Bay at an average speed of 8 knots and an average distance of 15–26 m between surface water recordings (**Table 10-10**).

Table 10-10. Time and distance summary for seven flow-through cruises of the Adaptive Protocol Study. Provided are the total number of surface water recordings, cruise starting and ending times, the total cruise time in hours, and the average and standard deviation of the distance between successive surface water recordings.

Date	Total Number of Records	Start Time (AM)	End Time (PM)	Total Cruise Time (hours)	Average ± Standard Deviation of Distance between Recordings
January 12, 2012	2,665	9:35	5:54	8.5	15 ± 9
January 19, 2012	1,611	8:57	5:15	8.2	20 ± 16
February 2, 2012	2,261	8:49	4:00	7.2	18 ± 13
March 1, 2012	1,614	9:11	5:26	8.5	25 ± 16
March 8, 2012	1,559	9:43	4:59	7.2	26 ± 17
March 21, 2012	2,177	9:32	5:54	8.5	19 ± 15
April 12, 2012	2,085	9:07	5:21	8.5	20 ± 15

Vertical Profiling Stations

On each of the seven cruises the research vessel stopped at 13–17 stations along the mid-estuary axis to conduct vertical profiling with the YSI 6600 (temperature, salinity, pH, DO, turbidity, Chl*a*), sample surface water for laboratory determinations of material concentrations, and to obtain large-volume water samples to process for zooplankton abundance and community composition. YSI 6600 recordings occurred at 0.5 m and then every meter (1.5 m, 2.5 m, 3.5 m, etc.) until reaching the bottom. Cruises that were interrupted by software, GPS, batteries, or pump problems had fewer vertical profiling stations. Stations 11 and 13 were missed on January 12 and Stations 11 through 14 were missed on March 1 (**Figure 10-23**).

Once the vessel was anchored at each vertical station, water from the flow-through system was dispensed into five bottles for laboratory determination of TN, TP, total suspended solids (TSS), Chl*a*, and dissolved inorganic nitrogen (DIN). All water quality samples were collected according to the District's Standard Operation Procedures and analysis was performed by the District's National Environmental Laboratory Accreditation Conference certified lab (SFWMD, 2011). Laboratory determination of Chl*a* concentrations were used to calibrate in situ estimates of Chl*a* obtained while profiling with the YSI 6600 for each of the seven cruises. A linear regression between laboratory and in situ Chl*a* concentrations was derived and applied as a correction to the in situ estimates from the vertical stations.

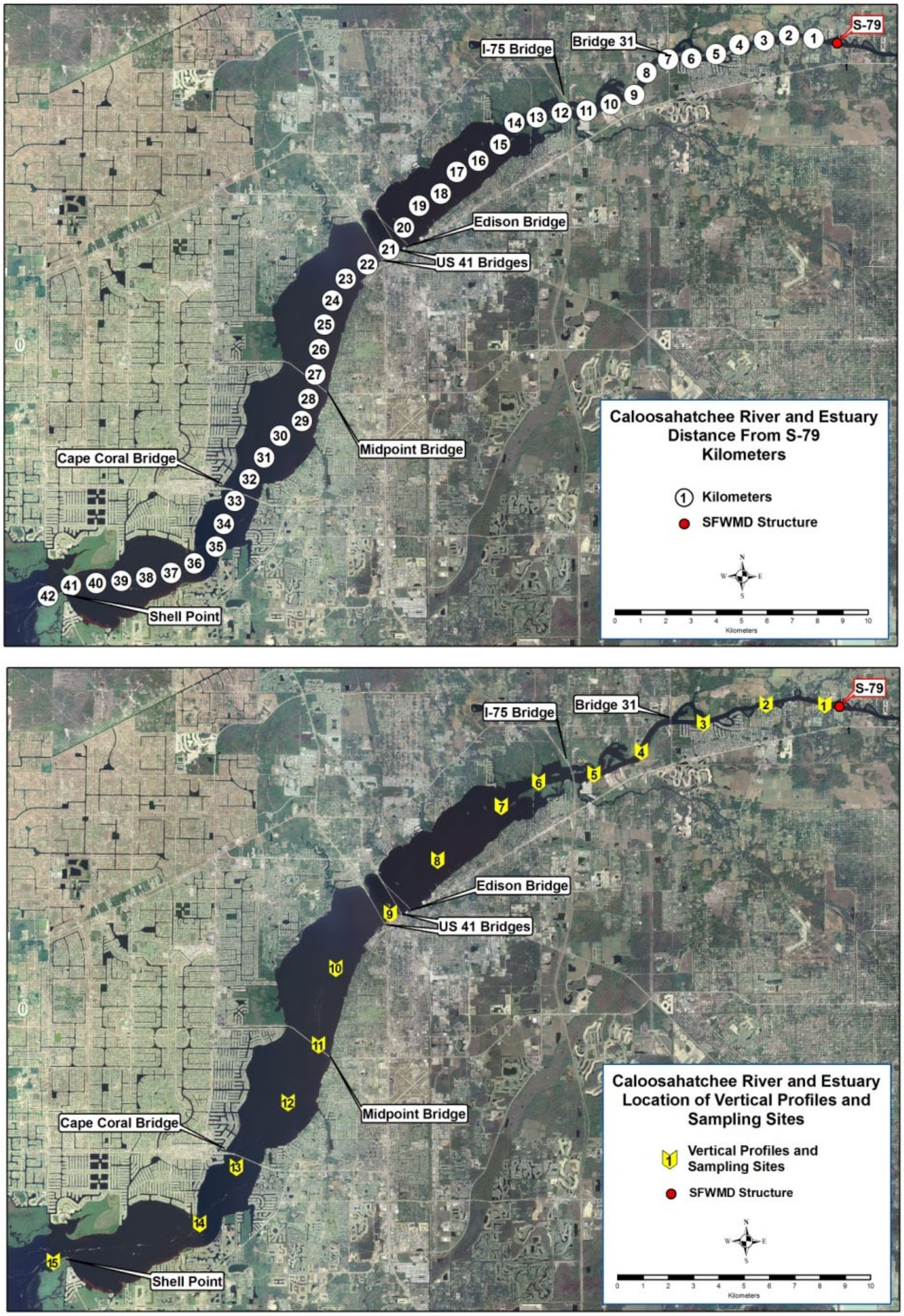


Figure 10-23. Maps of CRE depicting distance downstream from S-79 (white circles) for flow-through data (top panel) and the locations of vertical profiling stations (yellow chevrons) (bottom panel). All distances reported relative to kilometers downstream of S-79.

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A submersible pump was deployed at depth (maximum depth of 2.5 m) at each vertical station to obtain integrated water samples for zooplankton. Three 20-Liter (L) samples were pumped into plastic carboys. A 250-micrometres (µm) filter was used in the field when water samples contained substantial amounts of gelatinous ctenophores. Within 3 to 5 days of field efforts, the samples were filtered in the laboratory. Each of the 20-L samples was filtered through a 60-µm sieve in the field, the entrapped zooplankton was rinsed with deionized water into three 120-milliliters (ml) sample jars, and the samples were preserved in 5 ml of 5 percent formalin solution. The triplicate samples were labeled with project, date, station number, and a unique project collection number. Within 3 to 5 days of field efforts, the samples were removed from the formalin and prepared for weight determinations and/or enumeration. One of the triplicate samples was rinsed with deionized water and placed in 70 percent isopropyl alcohol for identification and enumeration of zooplankton taxa. The other two filtered 20-L samples were used for determinations of dry weight and ash-free dry weight (AFDW).

Samples for determination of zooplankton biomass were stored at less than 25º C. Whatman 4.7-centimeters (cm) glass fiber filters were triple rinsed with deionized water before filtering the zooplankton samples. The glass fiber filters were then dried at a constant temperature of 60 °C for 24 hours, weighed, put back into the oven for an additional 24 hours, and reweighed to ensure constant dry weights. To obtain AFDW, the dry weighed zooplankton filters were placed in a muffle furnace for four hours set at 500 °C. The combusted sample filters were weighed and the loss mass upon ignition of the organic component is referred to as the AFDW that was obtained using the following calculation:

$$\text{AFDW} = \frac{(\text{dry weight} - \text{filter weight}) - (\text{ash weight} - \text{filter weight})}{20\text{L}}$$

Data Analyses

Descriptive statistics derived from the flow-through variables of temperature, salinity, turbidity, in situ Chl*a*, and DO included the total sample size, data range, average ± standard deviation, and the location of the maximum value in kilometers downstream of S-79 for each of the seven cruise dates. Three variables of importance to the estuary conceptualization were salinity, turbidity, and Chl*a*. In situ surface water observations for these three variables obtained using the flow-through system were analyzed by distance relative to S-79 with San Carlos Bay at the oceanic end approximately 42.0 km downstream (**Figure 10-23**). Salinity profiles obtained at 15 discrete stations along the 42.0-km length were interpolated in two-dimensions (distance and depth) to examine variations in stratification and isohaline position among the seven cruises. Descriptive statistics were calculated to help assess surface water concentrations from the vertical stations that included TN, TP, TSS, DIN, and Chl*a*. The material concentrations were also assessed relative to station and cruise date. Zooplankton biomass was the final important variable as observations at each station and cruise were analyzed relative to distance from S-79 and the longitudinal patterns of Chl*a* and turbidity derived using the flow-through system.

Results and Discussion

Flow-through Data

The number of observations obtained using the flow-through system ranged from 1,559 to 2,655 among the seven cruises (**Table 10-10**). Temperature fluctuated by approximately 4–7 °C within the course of each of day with average values of 20.7–26.8 °C between January 12 and April 12. Maximum temperature values occurred approximately 11.3 km downstream of S-79. Salinity ranged from approximately 4.0–35.4 the first five cruise dates (January 12, January 19, February 2, March 1, and March 8) although salinity ranges were 6.6–34.9 and 9.0–30.3 (March

21 and April 12) (**Table 10-11**). Average temperature was greater than 26.0 °C only on the last cruise date (April 12).

Average salinity in the CRE increased from 13.5 ± 8.5 in January to 18.1 ± 7.4 in April 2012 (**Table 10-11**). Since it is a conservative property of the ocean, the greatest values were farthest from S-79 (greater than 41.0 km). The range of values and slope of the salinity versus distance relationships revealed that the estuary was increasingly salty over the seven cruises (**Figure 10-24A**). Salinity observations did not vary above 5 within the first 10–12 km, but increased to greater than 30 between 12 and 42 km on each of the first five cruises (January 12, January 19, February 2, March 1, and March 8). The freshwater inflow was evident in both the range in salinity values and the lateral and longitudinal oscillations downstream of 10 km. By contrast, salinity was comparatively homogeneous within first 10 km on March 21 and April 12. The salinity profile on April 12 in the absence of S-79 freshwater inflow increased smoothly from 10 to 35 along the length of the CRE.

In situ Chl*a* averaged 3.5–26.1 µg/L among the seven cruises with maximum concentrations located at an average of 14.8 km downstream of S-79 on five of the cruises (January 19, February 2, March 1, March 8, and March 21) (**Table 10-11**). However, the ranges (4.1–58.9 and 3.2–54.4 µg/L) and averages (16.7 and 17.8 µg/L) for in situ Chl*a* were much greater on the first (January 12) and last (April 12) cruises when maximum concentrations were located 2.6 and 3.7 km downstream, respectively (**Figure 10-24B**).

Turbidity values were generally low throughout the CRE ranging from 2.4 to 25 for all seven cruises (**Table 10-11** and **Figure 10-24C**). Observations ranged from 3.5 to 6.0 over the initial 10–12 km for all cruises. Values increased at approximately 15.0 km but were greatest in San Carlos Bay except on January 19 (15.7 km). Average turbidity was approximately 4.5 nephelometric turbidity units (NTU) except on March 8 (high values at 13.0 km and greater than 41.0 km) and March 21 (greater than 37.0 km). Spatial patterns of DO were not particularly revealing except that the maximum concentrations were far upstream at 3.8 and 1.8 km along with those of Chl*a* on January 12 and April 12 (**Table 10-11**). These locations were in close proximity to the zone of maximum Chl*a* on these dates.

Table 10-11. Descriptive statistics from CRE surface water sampled using the flow-through system from January to April 2012. Total sample size, range, average ± standard deviation, and the location of the downstream maximum value in kilometers from S-79. Included are water temperature, salinity, pH, turbidity, in situ Chl*a*, and dissolved oxygen (DO).

Date	Sample Size (N)	Range	Average +/± Standard Deviation	Maximum at S-79
Temperature [degrees Celsius (°C)]				
January 12, 2012	2,655	18.8–26.1	20.7+1.5	11.6
January 19, 2012	1,611	18.8–25.5	20.2+1.5	11.4
February 2, 2012	2,261	20.3–27.8	21.9+1.1	11.2
March 1, 2012	1,614	23.3–25.7	25.3+1.2	10.9
March 8, 2012	1,559	21.9–25.7	23.0+0.8	11.5
March 21, 2012	2,177	24.4–28.3	25.0+0.6	11.2
April 12, 2012	2,085	25.4–30.3	26.8+0.8	11.5
Salinity				
January 12, 2012	2,655	4.6–33.1	13.5±8.5	41.8
January 19, 2012	1,611	4.0–30.2	11.0±7.0	41.5
February 2, 2012	2,261	4.2–32.1	12.4±8.3	41.3
March 1, 2012	1,614	4.0–33.6	11.5±8.9	41.9
March 8, 2012	1,559	4.3–33.9	15.0±9.1	41.7
March 21, 2012	2,177	6.6–34.9	15.5±8.1	41.7
April 12, 2012	2,085	9.0–35.4	18.1±7.4	41.9
Turbidity [nephelometric turbidity units (NTU)]				
January 12, 2012	2,655	3.1–18.7	4.7±1.8	41.4
January 19, 2012	1,611	3.5–8.9	4.7±1.2	15.7
February 2, 2012	2,261	3.4–7.0	4.4±0.6	41.9
March 1, 2012	1,614	2.4–17.4	4.1±1.9	41.9
March 8, 2012	1,559	4.7–21.5	8.4±3.9	41.4
March 21, 2012	2,177	4.0–25.2	6.2±3.0	40.0
April 12, 2012	2,085	2.4–13.4	4.9±1.4	41.8
Chl*a* (µg/L)				
January 12, 2012	2,655	4.1–58.9	16.7±8.3	3.7
January 19, 2012	1,611	3.5–25.0	13.5±3.9	17.2
February 2, 2012	2,261	3.8–29.8	13.5±4.5	17.5
March 1, 2012	1,614	3.6–29.3	12.2±5.4	13.7
March 8, 2012	1,559	4.6–25.5	13.4±4.9	12.9
March 21, 2012	2,177	2.1–21.1	11.9±3.6	12.8
April 12, 2012	2,085	3.2–54.4	17.8±11.2	2.6
DO (mg/L)				
January 12, 2012	2,655	6.9–10.6	8.7±0.8	3.8
January 19, 2012	1,611	6.9–10.5	8.6±1.2	19.0
February 2, 2012	2,261	5.5–10.8	8.1±1.1	19.7
March 1, 2012	1,614	5.5–10.0	7.8±0.9	17.8
March 8, 2012	1,559	5.7–9.4	8.3±0.8	13.8
March 21, 2012	2,177	6.2–8.8	7.7±0.3	15.0
April 12, 2012	2,085	6.4–10.8	8.2±0.8	1.8

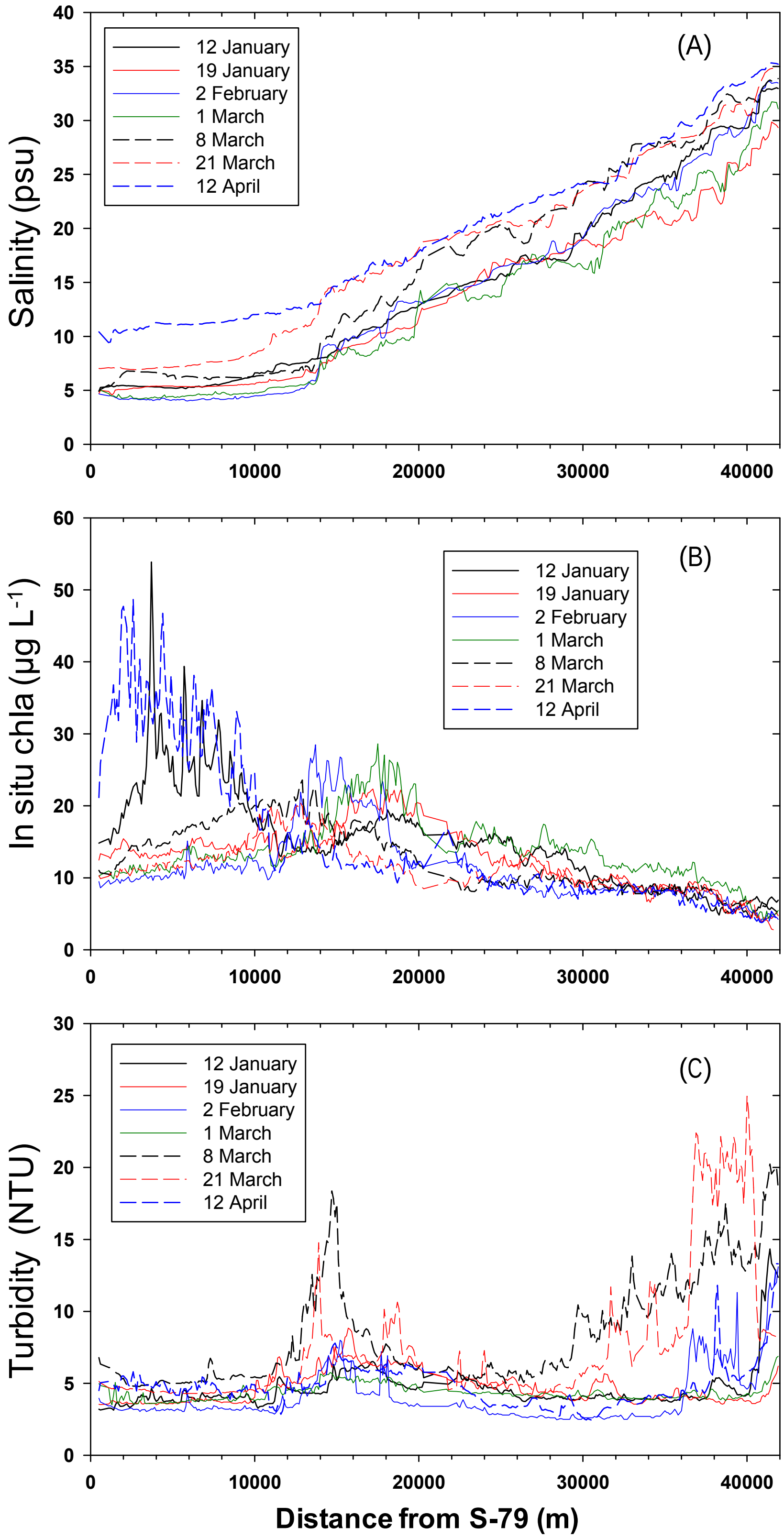

Figure 10-24. Distance versus surface water property plots for all seven cruise dates: (A) salinity in practical salinity units (psu), (B) in situ Chl*a* in µg/L or µgL^{-1}, and (C) turbidity in nephelometric turbidity units (NTU).

Vertical Profiling Stations

Two-dimensional interpolation of salinity profiles revealed subtle differences in estuarine hydrography among the seven cruises (**Figure 10-25**). The water column in the upper CRE (0–12 km) exhibited vertical salinity stratification on January 12. However, there was a clear horizontal salinity gradient on this day from 15 km downstream to San Carlos Bay where salinity approached 30 (**Figure 10-25B**). Freshwater inflows prior to January 19, February 2, March 1, and March 8 tilted the isohalines horizontally thereby slightly depressing the stratification in the upper CRE (**Figure 10-25C–E**). A lowered salinity lens (salinity less than 20) extended throughout the water column to approximately 30 km downstream on January 19, February 2, and March 1 depressing the exaggerated downstream horizontal stratification. CRE salinity structure was similar on the last three cruise dates (March 8, March 21, and April 12) (**Figure 10-25F–H**).

The range and averages for both TN (0.3–1.3; 1.0 ± 0.3 mg/L) and TP (0.04–0.1; 0.08 ± 0.03 mg/L) concentrations were similar among the seven cruises (**Table 10-12**). TN exhibited more inter-station variability in the upper CRE (Stations 1 through 7) than in the lower CRE (Stations 8 through 15) (**Figure 10-26**). While TP concentrations were both spatially and temporally consistent for the first six cruises, values were much greater in the upper CRE on April 12 (**Table 10-12**). By contrast, DIN concentrations in the upper CRE were much less on April 12 than observed on the other six cruises (**Figure 10-26**). Downstream of Station 7 (approximately 18 km from S-79), DIN concentrations were much reduced.

There were variations in maximum TSS concentrations as values on March 1 (15 mg/L) and March 8 (20 mg/L) were greater than the other dates (**Table 10-12**). The 20 mg/L peak on March 8 occurred at Station 7. TSS was much greater and more variable at Station 15 in San Carlos Bay (**Figure 10-26).** This agrees with the flow-through turbidity because San Carlos Bay is shallow with sandy sediments that are easily resuspended through a combination of boat wakes, wind waves, tidal currents, and freshwater discharge on different timescales.

Surface water concentrations were most variable among the seven cruise dates upstream of Station 9 (approximately 21 km downstream of S-79) (**Figure 10-26**). The Chl*a* maximum was observed to occur around stations May 7 (12–16 km) on a majority of cruise dates. Both the flow-through system and vertical profiling data revealed particularly high surface water Chl*a* concentrations in the upper CRE April 12 when freshwater inflow was negligible.

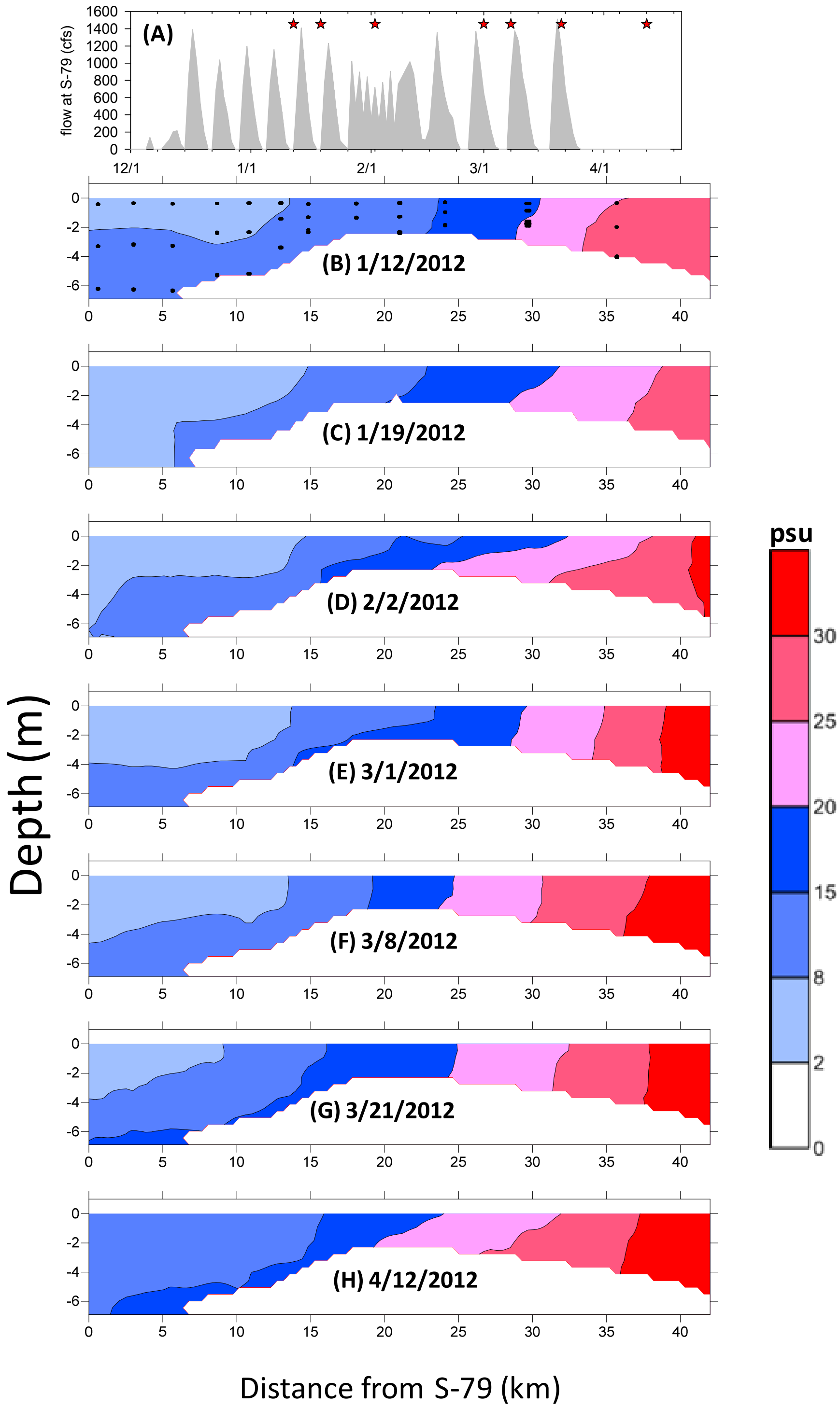

Figure 10-25. (A) Reproduction of S-79 inflow from January to April 2012 with cruise dates marked with stars. (B–G) Distance versus depth contour plots of salinity with locations of vertical profile stations (black circles). Depth was at least approximately 2.5 meters from 18 to 25 km downstream of S-79. See the *Methods* section for description of contour plots using the vertical profile data. Salinity ranged from 2 (blue) to over 30 (red).

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Table 10-12. Descriptive statistics from CRE vertical profile measurements made from January to April 2012. The total sample size, range, and average ± standard deviation are reported for TN, TP, total suspended solids (TSS), dissolved inorganic nitrogen (DIN), and Chl*a*.

Date	Sample Size (N)	Range	Average ± Standard Deviation
		TN (mg/L)	
January 12, 2012	13	0.3–1.3	1.0±0.3
January 19, 2012	17	0.4–1.3	0.9±0.3
February 2, 2012	17	0.3–1.3	1.0±0.4
March 1, 2012	14	0.4–1.2	0.9±0.3
March 8, 2012	17	0.3–1.1	0.8±0.3
March 21, 2012	17	0.3–1.1	0.8±0.2
April 12, 2012	17	0.4–1.2	0.8±0.2
		TP (mg/L)	
January 12, 2012	14	0.04–0.1	0.07±0.02
January 19, 2012	17	0.04–0.1	0.07±0.02
February 2, 2012	17	0.03–0.1	0.08±0.03
March 1, 2012	14	0.04–0.1	0.08±0.03
March 8, 2012	17	0.04–0.1	0.08±0.03
March 21, 2012	17	0.03–0.1	0.08±0.03
April 12, 2012	17	0.05–0.2	0.11±0.05
		TSS (mg/L)	
January 12, 2012	15	3.0–13.0	5.4±3.3
January 19, 2012	17	3.0–6.0	3.8±1.1
February 2, 2012	17	3.0–8.0	4.5±1.7
March 1, 2012	14	3.0–15.0	6.1±4.0
March 8, 2012	17	3.0–20.0	6.6±4.6
March 21, 2012	17	3.0–8.0	4.2±1.7
April 12, 2012	0		
		DIN (mg/L)	
January 12, 2012	15	0.0–0.5	0.2±0.1
January 19, 2012	17	0.0–0.4	0.2±0.2
February 2, 2012	17	0.0–0.4	0.2±0.2
March 1, 2012	14	0.0–0.3	0.1±0.1
March 8, 2012	17	0.0–0.3	0.04±0.1
March 21, 2012	17	0.0–0.2	0.1±0.1
April 12, 2012	17	0.0–0.01	0.02±0.01
		Chl*a* (µg/L)	
January 12, 2012	15	2.3–21.2	8.5±5.4
January 19, 2012	17	1.3–18.6	7.2±4.8
February 2, 2012	17	2.3–16.7	7.3±4.2
March 1, 2012	14	1.0–23.0	7.6±7.2
March 8, 2012	17	6.0–20.5	12.9±4.8
March 21, 2012	17	1.3–26.1	9.7±7.0
April 12, 2012	17	2.6–77.3	15.2±19.1

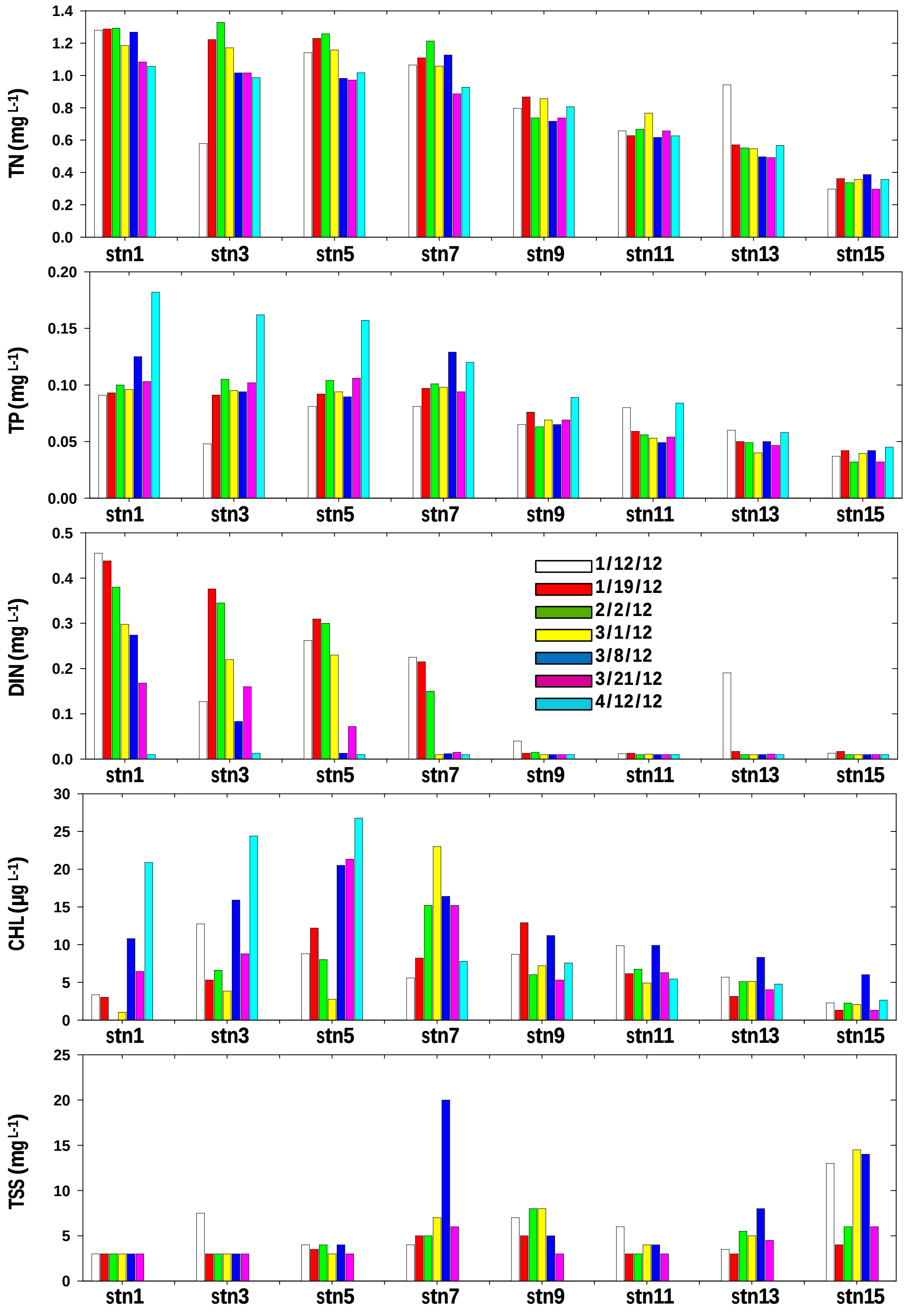

Figure 10-26. Grouped bar plots showing surface water concentrations in the CRE from January to April 2012. Only the odd numbered stations are shown for convenience (see **Figure 10-23**). Bars are color coded by cruise date. [Note: milligrams per liter = mg^{L-1}; microgram per liter = μg^{L-1}]

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Zooplankton

Zooplankton biomass ranged from 0.05–0.25 milligrams AFDW per liter (mg AFDW/L) along the length of the CRE for all seven cruises (**Figure 10-27**). There appeared to be two overall areas of maximum biomass located near 10 and 22 km downstream of S-79. Values determined from the last three AP Study cruises (March 8, March 21, and April 12) were greater than in the earlier cruises with a more definitive area of maximum concentration approaching 0.25 mg AFDW/L near 22.0 km.

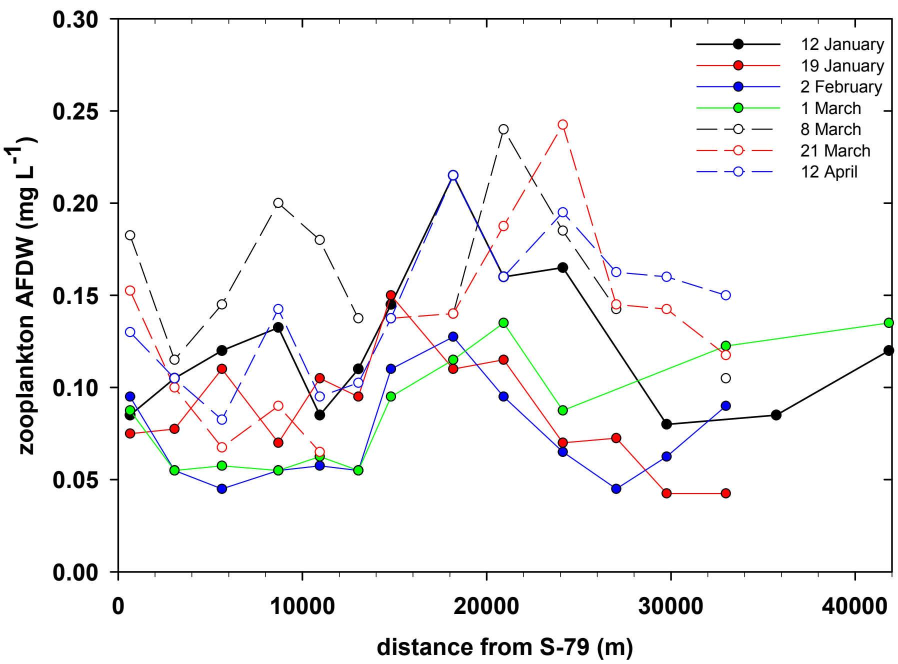

Figure 10-27. Zooplankton biomass in milligrams ash free dry weight per liter (mg AFDW/L or AFDW mgL^{-1}) derived from integrated vertical sampling at 13 to 17 stations in the CRE from January to April 2012.

Integrated Analyses

In general, results agree with the conceptual model depicted in **Figure 10-20**. An area of maximum productivity was observed with a peak in zooplankton located downstream of the Chl*a* maximum. The location of these peaks was not apparently influenced by the type of pulse release. All pulse releases had the same target average discharge (450 cfs). While the position and magnitude of the Chl*a* maximum in the CRE is known to vary with freshwater inflow (Doering et al., 2006), average flows during this study varied over the comparatively small range of only 450 cfs.

The observation of a Chl*a* maximum and a downstream zooplankton maximum on the six cruises when discharges were occurring is consistent with the hypothesis that low level releases stimulate productivity in the downstream estuary (**Figure 10-28**). By contrast, the observation of a comparatively large phytoplankton bloom after discharges had ceased (no flow conditions) indicates that freshwater inflow and phytoplankton blooms in the CRE need not be coincident. On its face, this observation is inconsistent with the conceptual model. The equally large bloom at the beginning of the study, just after discharges had begun is also hard to explain based on freshwater discharge alone.

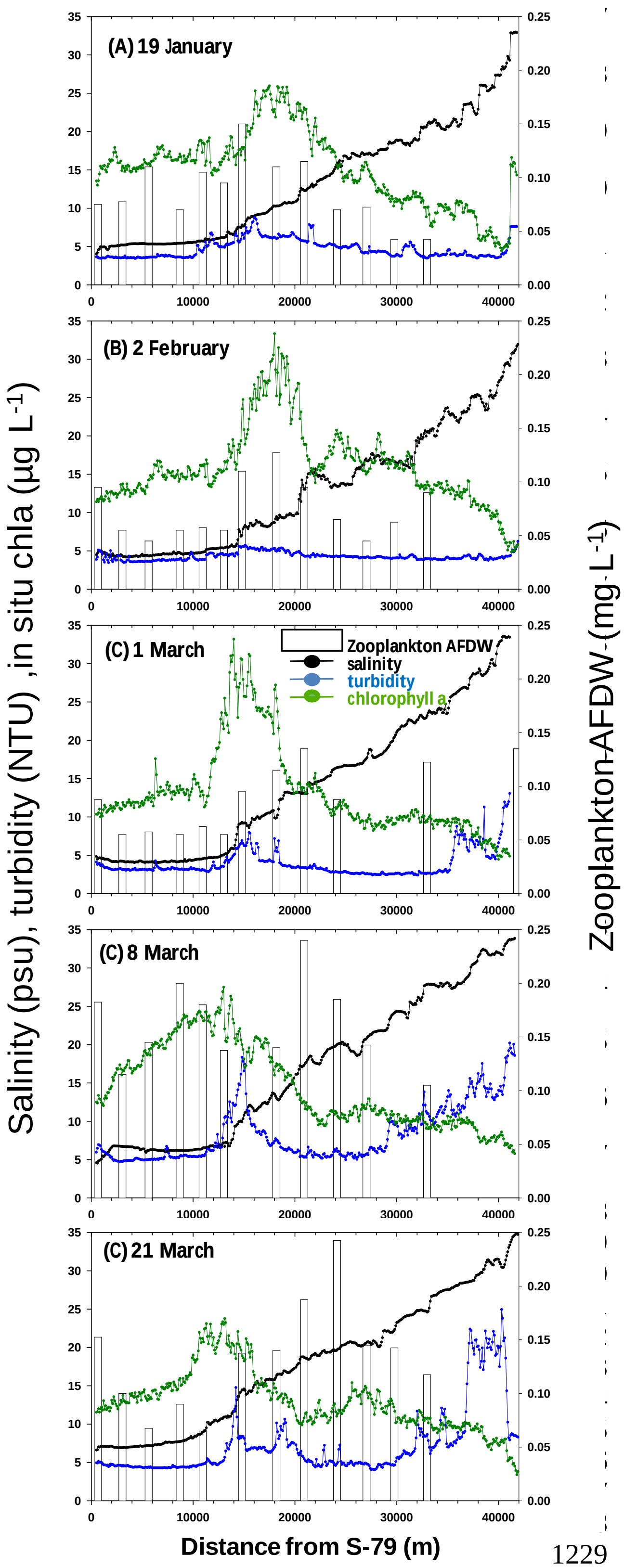

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Figure 10-28. Distance versus surface water property plots for four attributes — salinity, turbidity, in situ Chl*a*, and zooplankton biomass — on each of the five cruise dates from January to April 2012: (A) January 19, (B) February 2, (C) March 1, (D) March 8, and (E) March 21. Data from January 12 and April 12 are in provided in **Figure 10-29**.

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There are two distinct estuarine conditions that potentially led to these elevated Chl*a* in the upper estuary on January 12 and April 12 (**Figure 10-29**). The water column was vertically stratified on January 12 probably through the introduction of low levels of fresh water that occurred in December 2011 and early January 2012. Despite relatively low temperature, water column stratification can promote the remineralization of organic matter that can stimulate surface water phytoplankton production. By contrast, there was no freshwater inflow starting on March 26 with water temperature increasing to greater than 26 °C by the April 12 cruise. Recent analyses of District monitoring data indicated that there was great potential for phytoplankton blooms in the upper CRE when there is no inflow and temperature reaches 27 °C (Doering et al., unpublished data). This is a likely scenario to explain the high Chl*a* concentrations observed on April 12.

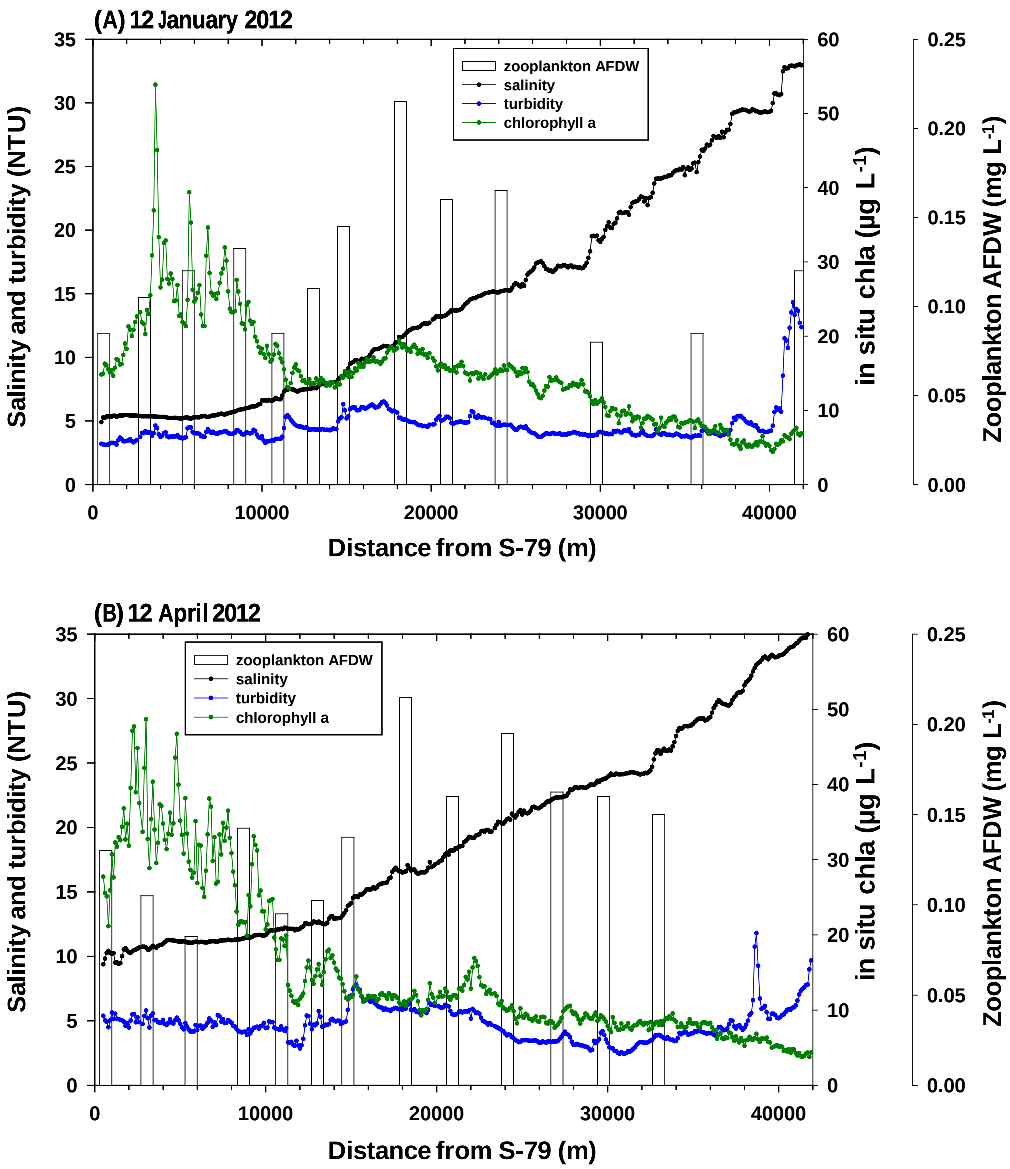

Figure 10-29. Distance versus surface water property plots for four attributes (salinity, turbidity, in situ Chl*a*, and zooplankton biomass) on (A) January 12, 2012 and (B) April 12, 2012.

Conclusions

- A common estuarine conceptual model suggests the input of fresh water and materials on timescales of days should stimulate food web dynamics in the estuary along the salinity gradient.
- Overall, the ecological gradients inherent in the conceptual model were apparent as the zooplankton biomass maximum was located just downstream of the Chl*a* maximum.
- Actual inflows through the S-79 structure were pulsed over a range of 0–4,500 cfs for a period of 2–4 days depending upon operational prioritization of water resources. Freshwater inflow at S-79 ceased on March 26, 2012.
- District staff utilized a combination of a flow-through system for rapid characterization of surface waters and a series of vertical profiling stations to detect changes in estuarine hydrography, water quality, and plankton attributes on seven independent research cruises.
- The freshwater inflow was evident in both the range in salinity and the lateral and longitudinal oscillations downstream of 10 km. Turbidity was greatest farthest from S-79 in San Carlos Bay where the comparatively sandy sediments are easily resuspended through boat traffic and wind waves.
- Extreme in situ Chl*a* concentrations approaching 60 µg/L were observed approximately 2.6 and 3.7 km downstream of S-79 on the first (January 12) and last (April 12) cruises, respectively.
- Two distinct estuarine conditions contributed to the upstream Chl*a* maxima. Water column stratification encouraged recycling that stimulated phytoplankton production on January 12. By contrast, there was no freshwater inflow as water temperature increased to greater than 26 °C by the April 12 cruise.
- The high in situ Chl*a* values in the upper CRE on January 12 and April 12 appeared to lead to greater zooplankton biomass in the mid-estuary. This supports the estuarine conceptual model. While zooplankton AFDW increased downstream of the Chl*a* peak, values were no greater than on the other cruise dates.
- Potential effects of low level freshwater releases during the dry season may not be fully represented by the conceptual model as evidenced by the observation that greatest phytoplankton biomass occurred when there was no freshwater inflow.
- The next step is to expedite field exercises and include fish larvae as a biological end point.

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